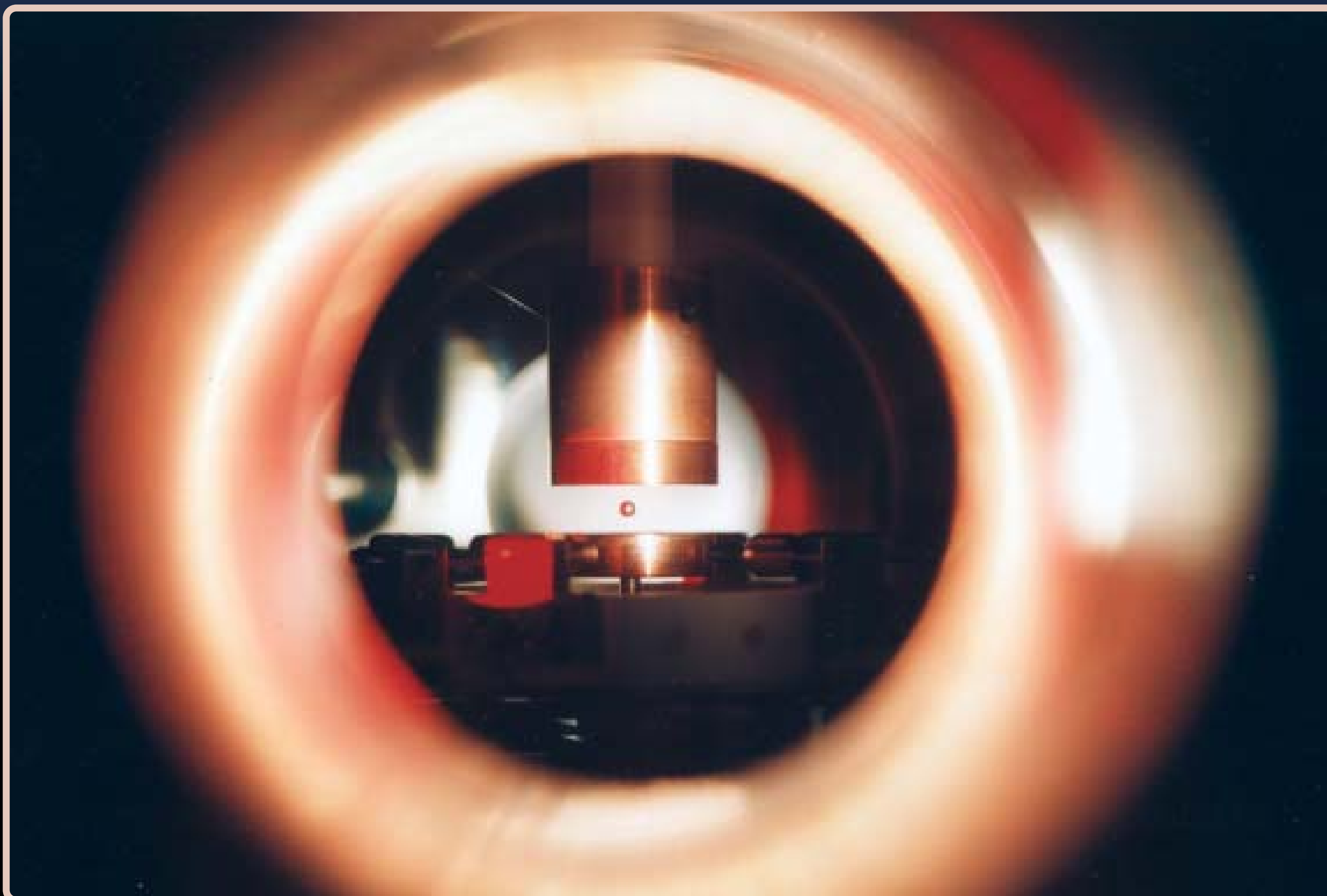
National Aeronautics and Space Administration

Space Research

Office of Biological and Physical Research

Spring 2004, Vol. 3 No. 2

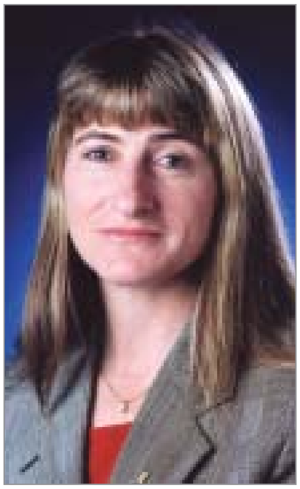


Space Research Reshapes Life on Earth

ALSO:

- Bone Loss in Space
- Wee Worms
- Liquid Crystal Bubbles
- Television to the Max

Letter from the Associate Administrator



On January 14, 2004, President George W. Bush announced a new vision for the nation's space exploration efforts. In support of this vision, NASA will

- implement a sustained and affordable human and robotic program to explore our solar system and beyond;
- extend human presence across our solar system, starting with a human return to the Moon by 2020 in preparation for the human exploration of Mars and other destinations;
- develop the innovative technologies, knowledge, and infrastructures to both explore and support decisions about the destinations for human exploration; and
- promote international and commercial participation in space exploration to further the United States' scientific, security, and economic interests.

The Office of Biological and Physical Research (OBPR), proud to be part of this endeavor, has begun the process of systematically reviewing its research portfolio to determine how its programs can best contribute products to realize the exploration vision. *Space Research* will reflect NASA's new vision with articles that showcase OBPR research in a very different light. Specifically, we want to communicate to readers that space research is essential to exploration and discovery, that everyone on Earth benefits from investments in space research, that OBPR is a global leader in space research, and that OBPR is an exciting place to work.

All of us at OBPR embrace President Bush's new vision for NASA. We welcome you along for the ride on this journey forward, and we offer our heartfelt thanks for your continued support.

Mary E. Kicza

Mary Kicza
Associate Administrator
Office of Biological and Physical Research

Hampton University
NASA Biological and Physical Research Outreach Project
Marshall Space Flight Center
1040 D Settlers Landing Road
Hampton, VA 23669
Telephone: (757) 728-6548
Fax: (757) 728-6559

MEETINGS, Etc.

TECHNICAL AND EDUCATIONAL MEETINGS
http://spaceresearch.nasa.gov/meetings.html

RESEARCH OPPORTUNITIES
NASA Research Announcements are listed at
http://research.hq.nasa.gov/code_u/code_u.cfm

PROGRAM RESOURCES
Office of Biological and Physical Research
http://spaceresearch.nasa.gov
- Latest biological and physical research news
- Research on the International Space Station
- Articles on research activities
- Space commercialization
- Educational resources

DESCRIPTIONS OF FUNDED RESEARCH PROJECTS
Science program projects
http://research.hq.nasa.gov/taskbook.cfm
Commercial projects (also includes links to a description of the Research Partnership Center Program and other information)
http://spd.nasa.gov/sourcebook/index.html

Table of Contents

Page 18

Page 27

On the cover:
Containerless processing allows researchers to study a wide range of physical properties of materials free from the influence of contact with container walls or instruments. Here a metal alloy is suspended between two electrically charged plates in NASA's Electrostatic Levitator. credit: NASA

Space Research is published quarterly by the **Marshall Space Flight Center (MSFC)** in conjunction with **Hampton University, COLSA, Corp.** and **Cherokee Nation Industries, Inc.** Address comments and newsletter requests to Editor, Space Research Magazine, Office of Biological and Physical Research, Code UP, NASA Headquarters, Washington, DC 20546-0001. Send mailing list additions and updates to *Teresa.Jones @hamptonu.edu*. Please provide your name, title, address, and phone number.

Space Research: *http://SpaceResearch.nasa.gov/spaceresearchnews.html*
Office of Biological and Physical Research: *http://spaceresearch.nasa.gov*

Spotlight

Engineers Host a How-To Session for Scientists and Specialists

credit: NASA

With the exception of the external monitors, the MSG Engineering Unit is an exact working replica of the Flight Unit. The Ground Unit is used for lower-fidelity testing and training.

NASA researchers from Glenn Research Center (GRC) in Cleveland, Ohio, and Marshall Space Flight Center (MSFC) in Huntsville, Alabama, as well as representatives from the Astronaut Office at Johnson Space Center in Houston, Texas, met with Microgravity Science Glovebox (MSG) engineers at the MSFC Microgravity Development Laboratory for a training session on MSG activation procedures.

The MSG used on the International Space Station (ISS) is a sealed workbench that allows astronauts to handle hazardous substances safely. In its first year of operation, four American investigations and four European investigations gathered valuable science data. This unique hands-on laboratory continues to be a valuable tool for collecting data in microgravity.

The specialists used the Ground and Engineering Units of the MSG for training. The MSG Engineering Unit is an exact replica of the Flight Unit and is used to train crew members before flight. Ground engineers use it to remotely diagnose and repair the Flight Unit by relaying instructions to the crew. The MSG Ground Unit is primarily used to test experiment hardware and train the crew before flight.

The scientists and specialists reviewed the many functions and features of the hardware, including g-LIMIT (Glovebox Integrated Microgravity Isolation Technology). g-LIMIT is an independent device within the MSG created to counter residual external forces that could interfere with experiment results. Created by whirring fans, thrusters, and crewmembers moving about the ISS, such forces are small but could be as disruptive as an earthquake to a protein crystal growth experiment. Most MSG experiments that need an undisturbed environment are placed on the g-LIMIT unit.

Investigators who attended the training program represented several projects, including Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsion (InSPACE) at GRC; Delta-L, an MSFC biotechnology investigation of protein crystal growth; and the Smokepoint in Co-flow Experiment (SPICE), also at GRC.

Preparations were made during the program to begin testing Hitchhiker Experiments Advancing Technology (HEAT) and “Arges,” a Dutch experiment that measures atomic densities in metal halide spectroscopy. Both of these European Space Agency payloads are scheduled to fly in spring 2004.

Recovered Memory Card Contains Missing Data

credit: University of Colorado at Boulder

This memory card was returned to MGM investigators during NASA’s search and recovery effort of Space Shuttle *Columbia* debris. Ninety-one space research experiments were conducted aboard STS-107 during its almost 16-day mission.

A memory card recovered from the debris of Space Shuttle *Columbia* (STS-107) was returned to Mechanics of Granular Materials (MGM) investigators led by Principal Investigator Stein Sture at the University of Colorado at Boulder (UCB). Although singed and warped, the memory card still contained experiment data. “The card looked as if somebody had taken a blowtorch and scorched it. You wouldn’t think there would be anything there,” says Buddy Guynes, MGM project manager at Marshall Space Flight Center, Huntsville, Alabama.

Susan Batiste, an MGM researcher at UCB, had trained *Columbia*’s crew and corresponded with them during the mission. When the data downlink did not work for the first experiment, Mission Specialist Kalpana “KC” Chawla offered to troubleshoot the problem, but Batiste insisted that Chawla stick to the experiment schedule because all the experiment data would be saved to memory cards. “We did not want to make her do extra work when we could get the data 2 weeks later and still be okay, so we had her press on,” Batiste explains. “It’s truly amazing; it makes you feel KC made sure to get us the data.”

The MGM team flew dry sand specimens twice on the space shuttle: STS-79 in 1996 and STS-89 in 1998. On STS-107, the investigators used wet sand to see how it would affect the experiment. Data downlinked via telemetry combined with the recovered memory card data, the previous two missions, and ground tests have given researchers considerable confidence in MGM’s results.

MGM researchers have added the new data into their cumulative database for understanding granular materials. “You don’t do many experiments in microgravity, so each one counts a lot. And this one counts even more since it was needed to verify nine other experiments. The information (on the scorched card) was as readable as if we had recorded it right next door,” MGM researcher Mark Lankton at UCB says. “This data proves key results from previous missions.”

The science team has submitted technical manuscripts to several research institutes, including the 42nd American Institute of Aeronautics and Astronautics’ Aerospace Sciences Meeting and Exhibit.

Gas-Fed Pellets to Fuel Exploration?

Two NASA-funded researchers are studying the effects of gravity on solid fuel combustion. Knowledge gained from this research could be used to explain phenomena related to explosions (for example, during lumber milling, in grain elevators, and in mine galleries) as well as to design solid fuel for safe and efficient use in hostile environments (for example, propulsion in space or within a lunar or martian living facility).

Fokion Egolfopoulos and Charles Campbell, both aerospace and mechanical engineering professors from the University of Southern California, Los Angeles, have measured the burning characteristics of various solid fuel particles in microgravity and Earth's gravity. Their experiments compare the consumption of solid fuel and gaseous fuel by using two laminar, smooth-burning flames in an opposed-jet setup. The bottom burner issues a low-speed gas to carry solid fuel pellets to the flame, whereas the top burner uses particle-free gas to fuel the flame. Depending on the thermal environment preceding the flame sheet and other physical aspects of the particles, some particles ignite and completely burn, whereas other particles exhibit an inert behavior. "Solid fuels burn more efficiently when broken into small, spherical particles," Egolfopoulos says. "The data from this research could definitely benefit fire-prevention practices in work environments that have the potential of collecting airborne combustible dust."

Several chemical processes take place during solid fuel combustion. Understanding the temperature effects is a first step toward improving fuel economy in vehicles (in space and on Earth) and preventing spontaneous combustion in vulnerable work environments. "This is sort of a walk-before-you-run kind of thing," Egolfopoulos says.

By using numerical simulations based on their experimental observations, Egolfopoulos and Campbell have created a model that can be used to predict the combustion of solid fuel particles in a gaseous stream based on thermal conditions and particle properties such as size, density, and velocity.

This summer, Egolfopoulos and Campbell will present a few previously unobserved phenomena stemming from their research at the 30th International Symposium on Combustion in Chicago, Illinois (July 25–30, 2004).

Fokion Egolfopoulos and Charles Campbell (University of Southern California, Los Angeles) used this opposed-jet configuration to study how gravity influences the combustion of solid fuels. Particle size, speed, and density were measured to determine the optimal conditions for efficient combustion. In reduced gravity, a low-speed gas was more effective for complete fuel consumption; however, under Earth's gravity, the bottom combustor needed a higher-speed gas to carry the pellets to the flame. The increased speed caused some fuel pellets to incompletely burn.

credit: Rosa Jaqueline Edwards

Readership Survey Results Announced

About 1 percent of the current *Space Research* subscribers participated in a recent readership survey — 113 of a total of more than 10,500 subscribers. Those who completed the survey were university professors (25), elementary and secondary school teachers (24), industry employees (17), NASA employees (8), other government employees (8), librarians (3), medical professionals (3), retirees (2), and others (23). The survey was drafted by the *Space Research* editorial board and coordinated by EEI Communications, Alexandria, Virginia.

Response was favorable toward the balance between technical and nontechnical information as well as between research details and practical applications. Readers responded favorably to the length and number of articles and the design of the publication.

Responses to the *Space Research* readership survey conducted in August and September 2003 indicate that subscribers are getting a lot of what they want in a magazine about biological and physical research in microgravity.

Some sections in the magazine appear to be not as useful to readers. In response, the *Space Research* editorial board and staff are reviewing ways to make the Profile stories about researchers more appealing; the Meetings, Etc., page, more timely (this information has been moved to a Web page that is updated regularly); and the Associate Administrator's letter more exciting.

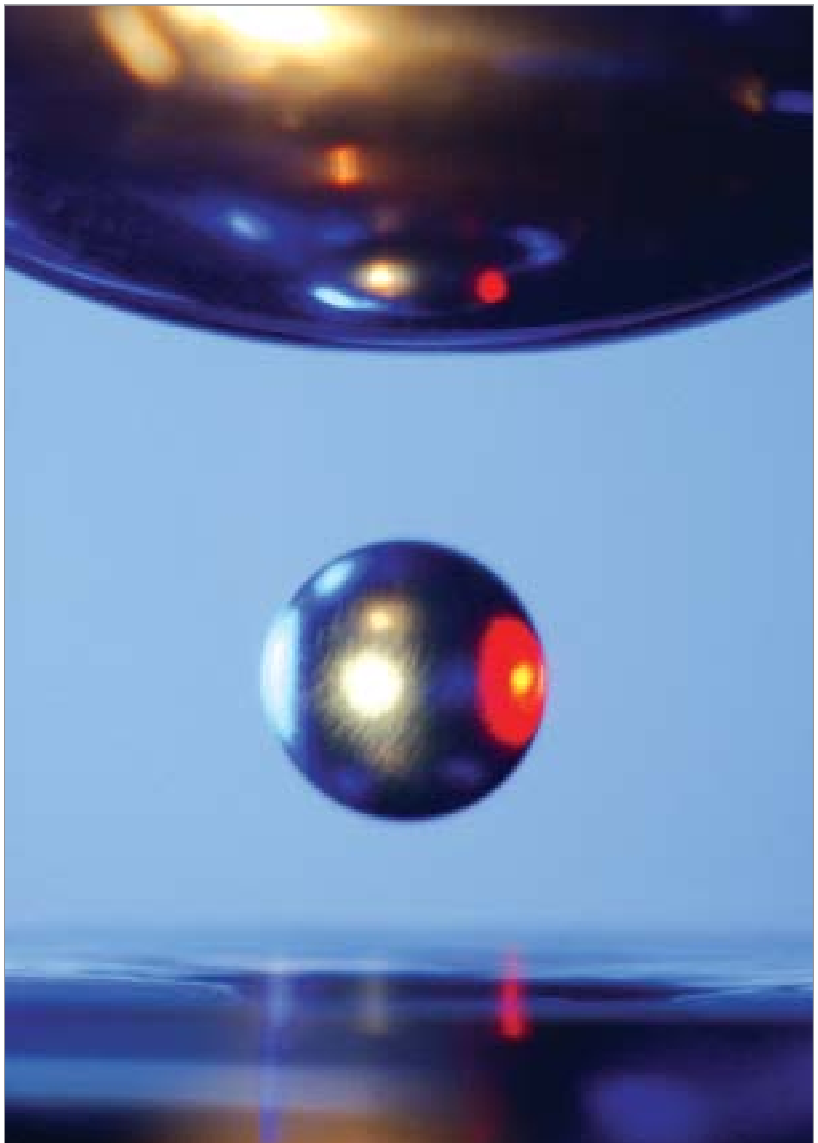
Those who took the survey enjoy many of the departments within *Space Research*. The overwhelming majority of respondents found the cover stories (like "Space research reshapes life on Earth" in this issue) to be extremely or very useful. Most survey respondents also strongly liked the Research Updates (like "Wee worms yield enduring science" and "Liquid crystal bubbles: platform for molecular research" in this issue). The Education & Outreach columns got a strong positive response from the majority of respondents, especially teachers. A large majority of respondents also found Spotlight articles (like the short pieces on this and the previous page) to be extremely or very useful.

Subscribers offered constructive feedback and suggested areas for improvement in a *Space Research* readership survey conducted last August and September.

credit: Rosa Jaqueline Edwards

Space Research Reshapes Life on Earth

From surgery in the Amazon basin to the creation of novel types of glass, space and microgravity research spur new technologies and unforeseen possibilities.



Containerless processing, in which materials do not touch the walls of a container, is used to study the forces that influence the formation of materials. Here, a sample of titanium–zirconium– nickel alloy is suspended by static electricity in NASA's Electrostatic Levitator.

credit: NASA

In a remote region of Ecuador, doctors operate on a patient while specialists in Virginia monitor the procedure via the Internet. In Michigan, emergency room doctors use ultrasound to make a diagnosis on the spot rather than send a patient for X-rays. In Illinois, a startup company manufactures a glass that replaces more expensive crystals in lasers. And in Colorado, researchers probe new ways to make hip implants that feel, act, and last like natural bone.

All of these advances have sprung from research sponsored by NASA's Office of Biological and Physical Research (OBPR), and they all hold the promise of life-changing improvements. Yet as impressive as these recent technological gains are, they are not unusual. They are part of a long tradition of NASA research that has already changed life on Earth.

A long tradition

Although NASA's space programs are well known, the commercial impact of space and microgravity research almost always surprises. Even Howard Ross is amazed. Formerly a combustion researcher at NASA Glenn Research Center in Cleveland, Ohio, Ross is OBPR's deputy associate administrator for science. For the past year, he has been documenting the earthly benefits of OBPR research. "I had no idea of all the technologies OBPR helped advance until I started my investigation," he explains. "NASA always focuses on the next challenge, so we tend not to look back at past achievements. Because there is often a time lag of a decade or more between research and any commercial product, we sometimes lose track of our successes."

Those many successes are the results of two distinct types of research. The first focuses on the practical aspects of space travel, that is, developing technologies that keep astronauts safe and healthy. For example, the medical telemetry systems developed in the 1950s for the first manned spaceflights have evolved into sophisticated stations used by nurses in hospitals around the globe to monitor the vital signs of many patients at once. Methodologies pioneered to ensure the safety of the Apollo astronauts' food are now used by federal agencies to monitor the purity of seafood and fruit juice and prevent the spread of "mad cow disease." Software programs written in the 1960s to test spacecraft designs for stress and heat tolerance today evaluate the performance of items as diverse as helicopters, Bose speakers, Nike running shoes, and Fender guitars. And NASA-funded research into miniaturized devices to find and study life in space during the 1970s led to patents that are still referenced by today's nanotechnology researchers.

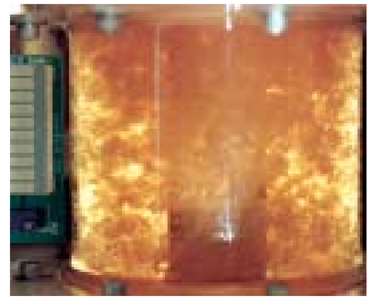
The second type of OBPR research asks fundamental questions about the behavior of life and matter where gravity is a mere whisper. Experiments that reveal the interplay of subtle forces masked by Earth's strong gravity may stand conventional wisdom on its head. For scientists, it is like removing a watch's face and seeing for the first time the mechanism that governs its motion.

Bioreactors

How exciting are rotating bioreactors? In an editorial entitled "Goodbye, flat biology?" the esteemed science magazine *Nature* suggests that they could consign glass petri dishes to the annals of history.

Petri dishes are the shallow curved glass plates used to grow cells and test new drugs since 1887. Cells grow well on the dishes but do not form the complex three-dimensional structures found in natural tissue.

In rotating bioreactors, however, growing cells develop specialized functions and self-assemble into complex three-dimensional (3-D) structures. The cells look and behave more like natural tissue than cells grown in a dish. By studying cells grown in bioreactors, biologists have uncovered valuable clues about how cells specialize, self-assemble, and grow. And for testing new medical treatments, such cells yield results that are far more realistic than cells grown in petri dishes.



Within five days, bioreactor-cultivated human colon cancer cells (shown), grown in microgravity on the STS-70 mission in 1998, had grown to 30 times the volume of the control specimens grown on Earth. The samples grown in space had a higher level of cellular organization and specialization. Because they more closely resemble tumors found in the body, they are ideal for research purposes.

credit: NASA

NASA's involvement with bioreactors dates to the 1970s, when researchers at NASA Johnson Space Center, Houston, Texas, speculated that cells cultured in microgravity would remain suspended and form 3-D structures. They then simulated microgravity conditions on the ground, using a rotating cylinder to gently circulate nutrients and prevent aggregated cells from settling.

By studying bioreactor-grown tissues, biologists have switched cancer cells between malignant and nonmalignant states and have gained new insights into neurobiology, atherosclerosis, and diabetes. Bioreactors have become an important part of cancer and biological research aboard space shuttles and the International Space Station. On Earth, NASA licensees have sold more than 6,000 bioreactors to researchers around the world.

Cell growth is one revealing example of fundamental research. In the 1970s, NASA scientists theorized that cells grown in microgravity would develop three-dimensional

Flame balls

For 40 years, scientists believed flame balls — small round spheres that burn only on their surface — were too unstable to persist. Then, in 1984, scientist Paul Ronney at NASA Glenn Research Center in Cleveland, Ohio, seemed to create some.

credit: NASA

Roughly the size of peas, tiny but stable flame balls exist only in microgravity. They may hold the key to more environmentally friendly combustion as well as answers to many fundamental questions about combustion.

Ronney was studying how flames behaved in the 2.2 seconds of microgravity created by dropping a canister of burning hydrogen down a 27.4-meter (90-foot) tower. He saw the flame break apart into what appeared to be small burning spheres that hovered like UFOs (unidentified flying objects). However, he needed the longer test times available on the space shuttle to confirm his findings.

Small enough for several to hover over a fingernail, flame balls are unusual. They are more stable than conventional flames and need very little fuel to remain alight. In fact, a flame ball created aboard Space Shuttle *Columbia* in 2003 was the weakest flame ever recorded. At 0.5 joules (0.5 watts), it emitted 100 times less energy than a typical birthday candle.

Flame balls have already altered our understanding of combustion chemistry. The *Columbia* flame ball experiment produced an 81-minute flame ball, which exceeded all predictions. It revealed that basic models of hydrogen consumption in lean fuel systems were wrong. It also exhibited new flame phenomena that will keep scientists searching for explanations for years to come.

structures that closely resemble natural tissue and reveal new information about cell growth and function. This insight led to the invention of the rotating bioreactor, a device that simulates microgravity conditions on Earth and enables researchers to understand many diseases better and test new drugs more accurately (see sidebar, Bioreactors, page 7). Studying cells in orbit has furthered researchers' understanding of tissue growth and how genes control cell function on Earth as well as in space.

Sometimes microgravity makes it possible to study phenomena too unstable to exist on Earth. Such was the case with flame balls, tiny hollow spheres of fire whose existence was predicted by theory in the 1940s but never observed in nature. Since they were accidentally discovered in microgravity during the 1980s, flame balls have upended accepted combustion theories and afforded new insights that may one day help improve the performance of car and jet engines (see sidebar, Flame balls).

Telemetry

Although past lessons learned from practical and fundamental space and microgravity research have already made their mark on commercial products and research techniques, today's OBPR research projects promise to change life on Earth soon. One of the most exciting advances is in medical telemetry, which may soon provide doctors and patients in rural areas and developing nations with remote access to outstanding medical specialists.

Biotelemetry (the automated measurement and transmission of medical data) dates back to the first live spaceflights in the 1960s, but long-term missions aboard the International Space Station (ISS) pose different challenges. Although astronauts can see Earth from orbit, they cannot count on timely help from home in the event of an emergency. What happens if an astronaut breaks a bone, punctures an organ, or bursts an appendix? While some crews include physicians, others do not — and no one doctor can be expected to have the expertise to deal with every potential emergency that could arise.

The quest for an answer began in 1989, when NASA was tasked with providing humanitarian assistance to Armenia after a devastating earthquake. The agency asked University of Texas Medical School Vice-Dean Ron Merrell to pull together a group of specialists to consult with doctors in the stricken region.

Merrell already knew something about remote medicine. His hospital provided televised medical classes and telephone consultations throughout East Texas. Neither method proved ideal for two-way audiovisual communication. Doctors might discuss a patient, but the specialist could not see diagnostic data or images. "It was only when NASA linked University of Texas, Latter Day Saints Hospital, and Fairfax Hospital with Armenia using telephone, television, and fax that we learned about what was and what was not practical in an interactive telemedicine format," he relates.

Merrell's interest blossomed. By 1991, he was holding interactive sessions with Russian physicians via two television studios and an Internet connection. "The Internet was so new, we barely knew what to call it," he says. The physicians eventually teamed to monitor astronauts on Space Station *Mir*.

Monitoring technology was subjected to a true "trial by fire" when a fire broke out aboard *Mir* on February 23, 1997. "At first the smoke was so dense, no one could see," Merrell recounts. "We used telemetry to monitor the crew's vital signs and oxygen and carbon dioxide concentrations to decide whether to evacuate. No one really knew how the astronauts were doing other than the telemetry and telecom teams."

The *Mir* fire strengthened OBPR's resolve to prepare for medical emergencies. Later that year, Merrell became the first director of the Medical Informatics and

A NASA-funded specialist in the United States watches a computer monitor showing laparoscopic images of a surgery at a remote medical unit in Ecuador. In phone contact with the surgeons, she guides them through the cauterization and removal of a gall bladder (shown on the monitor). Originally developed to handle emergencies during space missions, these remote surgical techniques are already expanding to provide specialist care to remote locations on Earth.

credit: Medical Informatics and Technology Applications Consortium (MITAC)

Technology Applications Consortium (MITAC), a Space Partnership Development Program research partnership center at Virginia Commonwealth University in Richmond. MITAC's goal is to find ways to respond to health crises in space. "What do you do with someone who is not fully trained and needs just-in-time software and education to perform a complicated task?" Merrell asks. "Our goal is to answer that question on Earth and pass the technology and protocols on to NASA."

That's how telesurgery began in the Amazon region of Ecuador. Merrell wanted to see whether a team of surgeons in an Ecuadoran operating room could identify organ images and share data about vital signs with a team of specialists in the United States. Although transmitting data is fairly simple, sending images with enough detail for use during surgery involves specialized equipment. Transmission is especially difficult when using international phone lines, which can transmit only a limited amount of information at a time.

Merrell began with a relatively simple procedure: the minimally invasive removal of a gall bladder. The operation relies heavily on computer images from a laparoscope, a tiny fiber-optic camera inserted into the body through a small incision under the navel. The images it takes are the surgeons' primary navigational tools during surgery. The laparoscopic images were transmitted from Ecuador to the United States. Using a telestrator — the same device John Madden uses to chart football plays for TV audiences — U.S. specialists circled organs and diagrammed cuts and stitches as they advised the surgeons in Ecuador. "It's as though we're all in the operating room," says Merrell.

From laparoscopic surgery, Merrell's U.S.–Ecuadoran team has advanced to more complex, more invasive surgery. The Ecuadoran doctors had to learn to mount and focus cameras so they could transmit the detailed information required by remote specialists and to conduct the operation without blocking the camera's view. U.S. specialists have also used telemedicine to guide Ecuadoran physicians in administering anesthesia, using a tiny fiber-optic camera to check the location of the gas tube in the trachea and then monitoring the patient's vital signs.

MITAC's techniques and protocols may one day help guide astronauts through complex medical procedures aboard the ISS. Meanwhile, MITAC is a leader among organizations pioneering telemedicine for use on Earth. The Virginia Commonwealth University Health System, for example, uses MITAC technology to give prisoners throughout the state immediate access to specialists without the security concerns or expense of visits outside the facility.

Because MITAC technology uses only a small amount of bandwidth, it is ideal for developing nations that have limited telecommunications capabilities. Its narrow bandwidth is also well-suited to transmitting information over mobile or satellite phones to medical technicians in emergencies. MITAC also has begun to spin off commercial products, such as software to monitor remote sensors and a sophisticated digital database for medical records that uses artificial intelligence to analyze and highlight important changes in patient health.

Ultrasound

Medical telemetry may one day guide orbiting astronauts through complex medical procedures. But how will they make a diagnosis? NASA's answer is already being tested aboard the ISS and giving trauma doctors information that is faster, cheaper, and often better than what standard diagnostic tools can deliver.

Researchers began searching for alternatives because traditional techniques were not practical for spaceflight. "If I'm a trauma center surgeon in a hospital, I can get an X-ray or CAT [computer-aided tomography] scan," says Scott Dulchavsky, chairman of the Henry Ford Health System Department of Surgery in Detroit, Michigan, and a NASA investigator. "But those machines are too heavy and use too much power for the ISS or a mission to Mars."

The machine must be not only small but also versatile. By the late 1990s, OBPR had listed more than 500 medical conditions that might occur on prolonged missions. They range from broken bones, kidney stones, and stroke to such space hazards as radiation exposure and bone density changes.

"My work with NASA tries to determine how many clinical conditions we could diagnose using ultrasound," Dulchavsky recalls. Although he teaches people how to use ultrasound — a technology that generates images from echoes created as sound waves bounce off tissue and bone — Dulchavsky had never thought of using it to diagnose trauma injuries. "On Earth, we would just ask for an X-ray, because every hospital has an X-ray machine."

Funded by an OBPR grant, Dulchavsky began looking at nontraditional uses for the technology. His findings

Portable ultrasonic diagnostic equipment like this device provides many of the same advantages as X-rays. NASA-sponsored technology and training could help small medical practices and first aid squads diagnose patients within seconds or send images to specialists for advice.

credit: SonoSite, Inc.

surprised him. "Our team looked at hundreds of patients," he explains. "We sent them for X-rays, but then scanned them with ultrasound before we got the X-ray pictures back. In some cases, such as chest X-rays and collapsed lungs, the [ultrasound] results were better than X-rays, and for broken bones, ultrasound is not superior, but it is equivalent." Today, thanks to Dulchavsky's work, thoracic ultrasound is used in major trauma centers throughout the United States and Canada.

Ultrasound offers additional advantages over X-ray technology to users on Earth. First and most important, it's fast. "When somebody is in distress, you can wheel it in and get a reading in 10 seconds," says Dulchavsky. Second, he notes that "because it does not emit radiation, you can diagnose pregnant women." Finally, at $20,000 to $30,000 per unit, ultrasound systems cost much less than X-ray systems.

But for emergencies in microgravity, ultrasound technology is only part of the solution. Dulchavsky also has to train people who lack medical experience to obtain quality scans. Ordinarily, ultrasound technicians complete more than 200 hours of training, plus have ongoing hands-on practice. Given their busy training schedule, astronauts do not have the time for such additional study.

And so necessity led to invention. Dulchavsky's team developed a multimedia training CD-ROM. "In 1 hour, we can teach the basic ultrasound concepts. We use state-of-the-art computer-enhanced anatomy, text-based references, and pictures. We show proper probe placement, pitfalls, and what the image should look like. Then we use skill-enhancing games to teach ultrasound fine-tuning and probe placement. We developed cue cards to help align the probes, and simple commands for controlling movement to achieve the best image."

Dulchavsky has successfully tested the CD-ROM with medical students, medical technicians, and even hospital housekeepers. Astronauts Peggy Whitson and Edward Lu generated test ultrasonic images aboard the ISS in 2003 with only minimal training. On future missions, astronauts will manage far more complex diagnostic tasks.

Meanwhile, Dulchavsky wants to train people to use recently commercialized portable ultrasound units on Earth. "Imagine the advantages if doctors in Iowa or India can obtain their own image and call a specialist for a consultation," he expounds. "Or a paramedic at an accident scene can phone an on-call expert to walk through an examination and determine whether an injury is just a bruise or a more serious condition that requires immediate helicopter evacuation."

The training CD-ROM itself could yield benefits beyond ultrasound. "We showed it at the American College of Surgeons meeting, and the education group went nuts. They will now use this NASA educational tool as a paradigm for future computer teaching tools," says Dulchavsky.

Containerless processing

Coping with issues that might arise while in orbit or in space pushes science and medicine to new achievements on the ground. Yet microgravity experiments that pry open nature's hidden secrets also lead to new technologies. Containerless processing — that is, processing in which materials do not touch the walls of a container — is a technique that reveals the forces that influence the formation of materials. Investigators are already gaining clues about creating artificial bone and glass for lasers by observing materials as they are processed in midair.

Containerless processing has several advantages over other synthesis methods. The atomic constituents of many materials can form different physical arrangements, known as phases, depending on temperature, pressure, and other processing conditions. Simply coming into contact with the wall of a container can cause a carefully processed material to spontaneously transform into an unwanted phase; suspending particles prevents this transformation.

Containerless processing seems like it naturally belongs in microgravity, where all matter floats. Yet containerless systems also exist on Earth, where acoustic, electrostatic, electromagnetic, or aerodynamic forces buffet materials to keep them aloft. The advantage of microgravity is that it lets scientists suspend materials while using only the tiniest of forces. Only then can researchers observe the interactions that turbulence and fluid flow might otherwise obscure — and use that information to make better materials on Earth.

Explosive reactions

Microgravity research has proven the best way to learn more about a hot, explosive reaction called self-propagating high-temperature synthesis (SHS), a technique well suited to making artificial bone. SHS occurs when two or more metal powders ignite, creating a chain reaction that fuses them into a new compound (usually a ceramic) while releasing enough heat to ignite more powders.

High SHS temperatures can produce porous ceramics at little cost, says John Moore, head of materials and metallurgy at the Center for Commercial Applications of Combustion in Space (CCACS), a NASA research partnership center at the Colorado School of Mines in Golden, Colorado. Unfortunately, the reaction proceeds rapidly and is difficult to control. “It’s all over in a few seconds,” he says.

The speed of the reaction makes SHS hard to monitor and understand. Containers also get in the way. Contact may create unwanted phases or soak up heat generated by SHS and inadvertently quench the reaction. Containerless processing eliminates these problems, but not those caused by convection.

Convection is the circulatory motion caused by nonuniform temperatures in fluids; powders in containerless systems act like fluids. Convection causes lighter, more buoyant elements of the fluid to rise and denser materials to sink. In SHS, with its high temperatures and rapid reaction times, convection acts like an explosion, driving lighter and denser phases apart.

Moving the reaction into microgravity, where gravity cannot pull down denser materials, would eliminate that problem. It would enable Moore to make SHS ceramics from a better mix of ceramics. Moore hopes to test his theory using Space-DRUMS (Dynamically Responding Ultrasonic Matrix System), a commercial containerless processing system from Canada’s Guigné International Ltd. in St. John’s, Newfoundland, that will be installed on the ISS. “We want to clearly understand the roles of gravity and containment on processing,” Moore explains. “Then we’ll find a creative way to simulate these conditions on Earth. To minimize buoyancy and convection, for example, we might add pressure instead of taking it away.”

The payoff may come in the form of artificial bone. Every year, hundreds of thousands of people have hip or knee replacement surgery. Unfortunately, metal and plastic implants do not last a lifetime. “Because they are stiffer than bone, they act as stress shields, absorbing all the stress instead of distributing it through the natural bone,” Moore explains. “Without that load at the interface of the implant and natural bone, new bone cannot grow.” Instead of bonding to the natural bone, the implant begins to grind it down. Over 10 or 15 years, the implant eventually loosens and causes pain. A second operation is more difficult and often not as successful as the first. No wonder doctors advise patients to delay the operation as long as they can.

Moore believes he can make implants from porous calcium phosphate, a material similar to natural bone. His goal is to use SHS to produce porous calcium phosphate–based materials that will be adsorbed into the blood as the new bone grows into the porous scaffold. It must have a good combination of phases to retain its strength, and at least half of its volume must consist of pores 200 to 500 microns (0.00787 to 0.01969 inches) in diameter. The pores must interconnect to allow blood flow, and their surface must scavenge calcium and phosphate ions from the blood to form new bone that bonds to the body’s natural bone.

Alternatively, Moore could use SHS to synthesize an amorphous glass reinforced with hard, minuscule ceramic particles that is strong and tough enough to use for dental crowns, smooth ceramic kitchen cooktops, and new types of optical fibers.

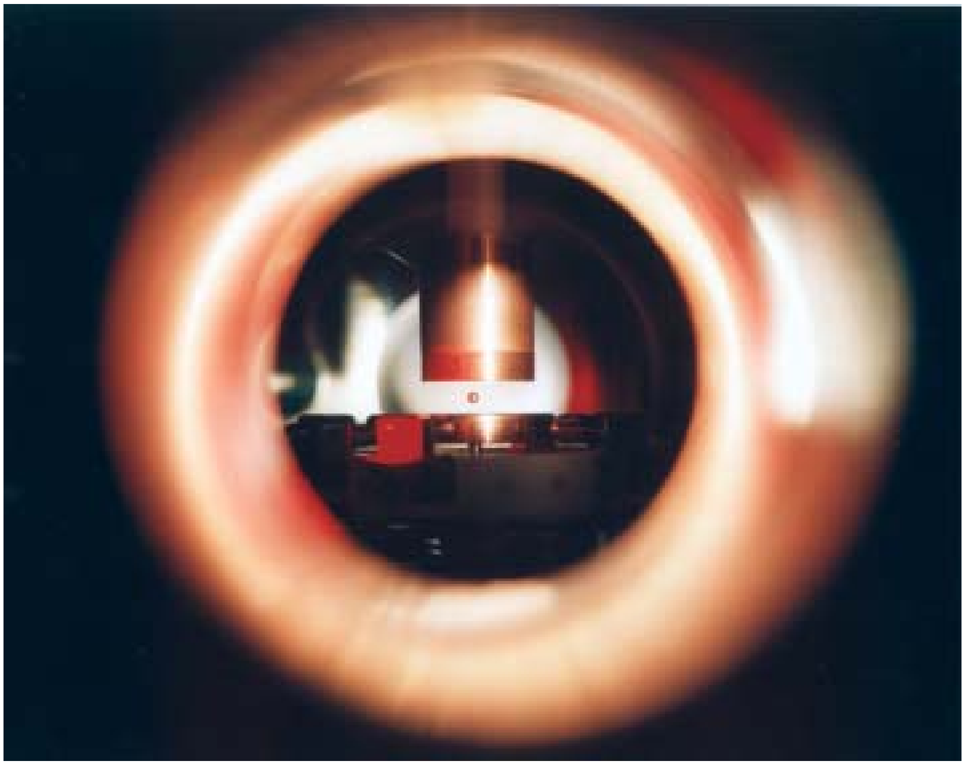
Moore’s challenge is complex. He has resolved some issues through tests aboard NASA’s KC-135 airplane, better known as the “Vomit Comet,” which simulates a state of microgravity while it hangs in freefall for up to 25 seconds during parabolic flight. Unfortunately, it takes longer than 25 seconds for some glass ceramic SHS reactions to solidify. When Space-DRUMS flies on the ISS, Moore will have time to unravel the secrets of SHS.

Spheres within spheres

Rick Weber, director of the Glass Products Division at Containerless Research, Inc., in Evanston, Illinois, uses containerless techniques to keep molten spheres of flowing glass from touching the walls of a reactor during processing. The result is REAl Glass, made from rare earth and aluminum oxides and some silicon dioxide, which can replace crystals used in lasers and optical communications.

REAl Glass is not easy to make. Its ingredients can form many different phases. Weber must create the molten sphere of the glass phase he wants — no unwanted phases. In principle, it is no more difficult than, say, cooking a soufflé inside a roasting turkey.

Weber’s recipe calls for undercooling — chilling the molten glass below the temperature at which it would ordinarily solidify. This process makes the material metastable, just barely able to retain its phase structure. Even



NASA's Electrostatic Levitator uses static electricity to suspend a sample inside a vacuum chamber while a laser heats the sample until it melts. It enables scientists to observe processing without the effects of sample contact with a container wall, giving researchers clues for optimizing conditions when making novel materials.

credit: NASA

a small change in energy or temperature could cause its atoms to suddenly rearrange themselves into another (undesirable) phase; using a containerless process to avoid contact interactions prevents such changes.

Working with the Electrostatic Levitator at NASA Marshall Space Flight Center in Huntsville, Alabama, Weber has produced small amounts of REAl Glass from undercooled melts. Unfortunately, convection in equipment on Earth creates too much turbulence to monitor how the glass forms and flows as it absorbs materials from the melt. In microgravity, in the absence of convection, these reactions are much easier to study.

Back on Earth, Containerless Research now casts the glass rods and plates needed to explore new applications. Weber is hoping a future experiment on the ISS will enable him to learn enough about reaction kinetics to increase the amount of glass he can process. These new kinds of glass may revolutionize the world of lasers, which typically use crystals to amplify light. Laser power, says Weber, is limited by the number of dopants (intentionally added impurities) the crystals hold: Too few, and the laser lacks power; too many, and it quenches power. In REAl Glass, however, the rare earth metals that comprise the physical structure of the glass also act as dopants. Thus, Weber can make glass materials with levels of dopants that are higher and more homogenous than those of crystals. The resulting glass can then generate more power without quenching.

Higher power density means smaller, better lasers. REAl Glass also should cost less than crystals. Moreover, by varying the types of rare earth elements and their concentrations, Weber will be able to tune his lasers to a broad range of frequencies. This fine-tuning may enable him to create inexpensive glass materials that are designed to cut particular types of tissue or bone in much the same way that dentists use different drills for specific jobs.

Industrial lasers could be tuned to eye-safe wavelengths for materials processing or for marking and sealing assemblies. They might play a role in computers that run on light instead of electricity and could drive down the cost of optical communications and computer networks.

Unexplained growth

Containerless processing promises to unveil secrets for making better materials for use on Earth, yet not all OBPR research has an immediate practical end. As Ross notes, it may take years or even decades for the applications of some fundamental research to become apparent. Meanwhile, fundamental research continues to add to our understanding of this complex universe and gives microgravity an opportunity to astonish. It becomes clear when discussing the growth of moss in microgravity with Fred Sack, a professor of plant biology at Ohio State University in Columbus. His work has put a surprising spin on a topic most people think they already understand.

Everyone learns that plants bend toward sunlight as they grow. Yet few people have considered how a plant's roots "know" to grow downward. Plants apparently "sense" gravity through plastids, modified chloroplasts containing dense starch that sinks to the bottom-most part of root cells. Somehow, this action communicates to the plant which way is down. Sack wondered what would happen to plastids in microgravity, and what plants would do if two key determinants of their growth — gravity and light — were taken away.

For his experiments, Sack used *Ceratodon* moss. The plant's single-celled phase is so small that hundreds of filaments fit on a 6-centimeter (2.4-inch) petri dish and its

Moss experiment survives *Columbia* crash

On the morning of February 1, 2003, Fred Sack of Ohio State University, Columbus, stood beside a runway at Kennedy Space Center in Cape Canaveral, Florida, waiting to retrieve his second series of microgravity *Ceratodon* moss experiments from Space Shuttle *Columbia* (STS-107). When it was clear that the space shuttle was not going to return, Sack and other researchers were led away. Then, 3 weeks later, a search team found a piece of hardware from Sack's moss experiment. Over the next 2 months, seven of the eight brick-sized aluminum canisters that had flown aboard *Columbia* were recovered.

All the canisters displayed evidence of their 67,000-meter (200,000-foot) hurtle through Earth's atmosphere: Their aluminum shells were pockmarked, and one canister revealed a gash that had allowed rainwater to enter. Inside the containers, the gel used to stabilize the position of the moss had melted during descent and then resolidified after reaching Earth.

Despite the damage the canisters sustained, 86 of the 87 cultures recovered were still intact. Many cultures had mashed and clumped together, but Sack was able to identify some spiral growth patterns. "It amazed us that the cultures survived such harsh treatment. Evidently, the fixative applied by the astronauts maintained the mechanical integrity of some of the cultures. This gave us a glimpse of how the moss grew and what the insides of the moss cells looked like," says Sack.

More ground-based and perhaps flight work will be needed to understand the results in full context. Meanwhile, Sack and the rest of the world can only marvel at the survival of the specimens.

upward growth fits in a 10-micron (0.00039-inch) hemisphere. This moss has an especially interesting system because not all of its plastids fall to the bottom of its root cells. "This shows that the cell is somehow controlling which ones fall and how far," says Sack.

In microgravity, Sacks expected that plastids would disperse randomly throughout the moss. Instead, when he retrieved his first microgravity experiment from Space Shuttle *Columbia* in 1997, he found the plastid distribution uneven.

Sack suspects he knows what happened. Cells contain a network of protein "cables" called the cytoskeleton. Plastids and other heavy bodies such as the cell nucleus grip these internal structures and move about by using chemical reactions similar to those in human muscles. Researchers believe this system may have evolved to keep the different internal structures within a cell from stratifying simply by weight.

Sacks' experiment results support the idea that this network exerts forces on heavy organelles. "Taking gravity away apparently unmasked the default mechanical forces within the cell," says Sack. "This tells us that gravity normally counteracts forces inside cells that are not revealed until gravity is taken away."

Sack also expected that moss germinated in microgravity without light would grow randomly, like a tangle of threads. It had proven true for virtually all plants previously grown in microgravity. Instead, *Ceratodon* moss formed clockwise spirals. "This is the most dramatic example of nonrandom plant growth ever seen in microgravity," he says.

Why does this moss spiral? It is likely the cells somehow communicate with one another, Sack speculates. Maybe spirals are an optimal distribution for spreading over the ground without overlapping filaments. Whatever the reason, this observation in microgravity provided a window into moss's evolutionary past, says Sack. The spiral behavior likely existed before the gravity response evolved. "This mechanism continued to function all these ages. It was probably superceded by the more powerful gravity response."

All life has evolved under a constant gravitational field. Perhaps other organisms grown in microgravity will display different responses, revealing hidden rules about life on Earth.

Who knows where these findings will lead? Maybe researchers will find a way to use this knowledge to grow trees whose roots dig deeper, faster, and farther than ever before, or to alter the shape of crop growth to improve harvest or yield. After all, the practical results of flame balls — improved jet engines — were not apparent until researchers had a chance to poke, prod, and digest what they had learned, says Ross. That is the true magic of microgravity research: It is a window onto the unknown, a door into the unexpected. And an opportunity to challenge and change the world as we know it.

Alan S. Brown

To learn more about flame balls (and watch a short video of them in motion), visit *http://spaceresearch.nasa.gov/general_info/31jan_kelly.html*. A good starting point for information about bioreactors is *http://science.msfc.nasa.gov/newhome/br/bioreactor.htm*. The Medical Informatics and Technology Applications Consortium (MITAC) maintains an extensive Web site at *http://www.meditac.com*. Scott Dulchavsky's space-based work on ultrasound is summarized at *http://www.nsbri.org/Research/2001-2003/MedSysProj9.html*. The Center for Commercial Applications of Combustion in Space (CCACS) provides a broad range of combustion-related information at *http://www.mines.edu/research/ccacs*, and Guigné International Ltd. presents information about Space-DRUMS at *http://www.guigne.com/space*. Containerless Research describes REAl Glass and other products at *http://www.containerless.com/realglass.htm*. Fred Sack's microgravity research on moss growth is described at *http://www.biosci.ohio-state.edu/~plantbio/Faculty/sack.htm*.

New Technology Sheds Light on Bone Loss in Space

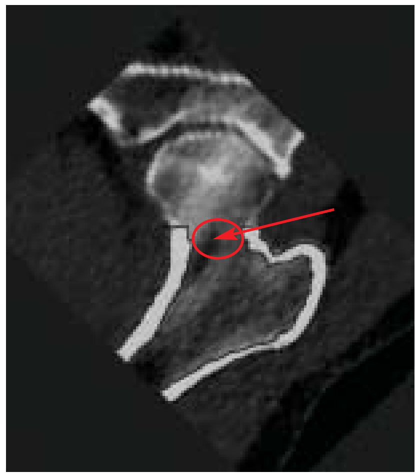
The microgravity environment aboard the International Space Station causes significant loss of bone mass in astronauts during long-term missions. A study using a new type of imaging technology is helping researchers understand bone loss, bringing the hope of better prevention to astronauts and the millions of people on Earth who have osteoporosis.

To friends and family members greeting them, astronauts stepping out of the space shuttle after a stay aboard the International Space Station (ISS) look just like they did the day they said goodbye. Inside, though, they've changed. Their once-strong bones have weakened, in a process similar to bone loss in the elderly. The decrease in bone mass that occurs isn't enough to cause fractures during or after a typical ISS mission, but it could be a serious risk for the much longer journeys that would be needed to reach Mars. NASA scientists believe that this risk can be overcome to bring humans one step closer to the Red Planet.

Scientists discovered the link between bone loss and prolonged spaceflight 30 years ago, during the Skylab missions. Premature bone weakening is a natural response to microgravity, the near-weightless environment experienced in orbit. Bones that make up the skeleton, like the muscles that attach to them, respond to loading. On Earth, work performed against gravity helps strengthen bone by loading the skeleton as we run, jump, and walk. The opposite happens in microgravity; because the astronauts are in a state of freefall, the bones do not experience the constant loading conditions they are exposed to on Earth. Bones affected most are in the areas of the skeleton that typically bear the most weight on Earth: hips, ankles, and spine.

"Astronauts lose bone at a rate of about 1 percent from the vertebrae and 1.5 percent from the hip every month they're in orbit," says Thomas Lang, an associate professor in the Department of Radiology at the University of California, San Francisco, and a NASA-funded researcher studying bone loss in astronauts. "At this rate, a person with a 6-month flight would lose about 9 percent of the bone mass in the hip."

Until recently, astronauts' only protection against bone loss serious enough to increase their risk of fractures was their relative youth, exercise programs on the ISS, and limited time (4 to 6 months) in orbit. "Even if they endure significant loss of bone during an ISS stay, astronauts' bones are still fairly strong," Lang says. But the same could not be said of astronauts who might undertake a much longer mission. NASA scientists estimate a trip to and from Mars would take 240 to 580 Earth days, all spent in microgravity or the reduced gravity of Mars. Unless bone loss can be prevented, even the shortest travel time would be risky. "If we don't develop effective countermeasures, it would be a serious problem for longer spaceflights," warns Adrian LeBlanc, a professor at Baylor College of Medicine in Houston, Texas, and director of the Universities Space Research Association's Division of Space Life Sciences.



This image of the upper femur (thigh bone) shows the outer layer of dense cortical bone, outlined in black, and the inner layer of more porous trabecular bone. Astronauts, like people who have osteoporosis, lose the most bone in the trabecular region of the femur. The greatest bone loss occurs in the femoral neck (indicated by the red arrow).

credit: Thomas Lang

Bone dynamics

LeBlanc is working closely with Lang and other NASA researchers to develop effective ways to prevent or minimize bone loss in astronauts. Lang's piece in the puzzle is to use bone density imaging to better discern the changes that occur in bone in response to microgravity.

Although it may appear to be as animated as a rock, bone is living, everchanging tissue. Bone-building cells called osteoblasts constantly build new bone, whereas bone-destroying cells, osteoclasts, destroy old bone. In humans, buildup outpaces breakdown until about age 30, when bones reach their maximum density. After age 35, bone begins to break down faster than it is replaced in a process called resorption. (To visualize this process, imagine that the inner core of a bone [trabecular bone] is pumice stone. Resorption diminishes the amount of hard material, making the holes larger and weakening the overall structure.) In men, the rate of resorption increases very little throughout the aging process. In women, however, the rate of resorption accelerates during the years around menopause, and then returns to a gradual increase similar to that in men. The resorption process is accelerated during long-duration space travel, and the associated reduction in bone density could make astronauts more susceptible to bone fracture.

Osteoporosis fractures develop when bone loss is great enough to make bones brittle. Half of women and 12 percent of men over 50 suffer an osteoporosis-related fracture in their lifetime. New drug treatments and exercise help build bone mass but don't cure osteoporosis. "Better measurements of how bone density and geometry change with long-duration microgravity exposure will improve our understanding of the effect of reduced physical activity on the skeleton, which may yield insight into how bone changes with age and physical disability," Lang explains.

New use for an old technology

Lang's 4-year-old study compares the bone density of male and female astronauts before, immediately after, and 1 year after 4- to 6-month missions aboard the ISS. As of January 2004, he had examined 16 astronauts before and after spaceflight; 8 had been back long enough for him to also measure their density 1 year later. Lang continues to assess crewmembers as they head to and return from the ISS.

Advances in technology are helping Lang make new discoveries about the changes that bone undergoes in microgravity. Before Lang began his research, astronauts' bone density was measured with dual-energy X-ray absorptiometry (DXA), the same technology that most physicians use to diagnose osteoporosis. Yet DXA can underestimate bone loss because it provides a composite measurement of the inner (trabecular) and outer (cortical) bone compartments, which respond differently to physical activity. Lang overcame this drawback with quantitative computed tomography (QCT).

QCT resembles the conventional computed tomography (CT) technique in that it uses radiation to scan cross sections or "slices" of tissue, thus enabling the measurement of density in small sections of bone, as opposed to the entire bone (which DXA does). The difference between QCT and conventional CT is that QCT allows images to be presented quantitatively. Lang's study results have shown a significant difference in bone loss between the porous trabecular bone and the dense cortical bone. The results of DXA analysis indicate only that astronauts lose an average of 1.5 percent of bone mass per month from the upper end of the femur (thigh bone), just below the ball of the hip joint. Scans of the upper femur with QCT reveal that the monthly rate of loss is 1 percent in the cortical bone but 2.5 percent in trabecular bone. In vertebrae, however, the results of examination by QCT indicate that cortical and trabecular bone resorb at the same rate. "Simply using DXA does not take into account what is happening in the bone interior," Lang explains.

The combination of technological advancement and this startling discovery is important news for the estimated 10 million Americans who have osteoporosis. Like astronauts, people with osteoporosis lose more trabecular than cortical bone, particularly in the upper femur, where most hip fractures due to bone loss occur, according to Lang. Although it is not used as widely as DXA, QCT is used at many centers throughout the country to diagnose osteoporosis and evaluate its treatment. The advent of new approaches like Lang's may make QCT an even more important tool in the future.

Variation in bone loss

Lang has found that although every astronaut experiences some bone loss, the amount varies tremendously. Most lose 1 to 2 percent per month, yet some on a 6-month flight lost 20 percent of the bone mass in their lower limbs. "It may be genetic," Lang suggests. "It could be a variation in diet. There are many variables."

Perhaps the most obvious variable is exercise. However, comparisons of crewmembers with different exercise patterns have been surprising. Some who had little physical activity beyond their work experienced minimal bone loss, yet others who routinely pedaled an exercise bicycle and ran on a modified treadmill lost as much bone mass as their colleagues who did not exercise.

Lang and LeBlanc still believe that exercise can help preserve bone mass. Studies have shown it helps people who are bedridden for long periods. Astronauts in microgravity simply may need to do more exercise, or exercise with greater resistance. "For a number of reasons there is considerable variation in the amount and type of exercise performed on a daily basis," Le Blanc says. "Developing a more effective exercise prescription is an area of high priority for NASA scientists."

Predicting fracture risk

Finding countermeasures against bone loss in astronauts is necessary to reduce the risk of fractures, but how, exactly, is such risk assessed? If a crewmember loses 30 percent of bone mass in the upper femur, will that hip break when the astronaut steps out of the spacecraft? Will a colleague who lost 22 percent of bone mass break a hip? And how do variations in resorption of trabecular and cortical bone affect fracture risk?

Lang hopes to answer such questions in much the same way an engineer determines that a particular bridge design can hold five cars and one 10-ton truck. An engineering computer program will crunch data on bone dimensions and density to assess their strength. "The ultimate goal is to create an index to estimate the risk of fracture," Lang says.

Another goal of the study has been to compare ultrasound measurements of bone loss in the heel to QCT measurements of loss in the spine and hip, which are more prone to fractures. Ultrasound devices are compact and inexpensive and do not use ionizing radiation, making ultrasound an attractive technology for onboard bone measurements. By having astronauts use these machines in flight, NASA physicians on Earth could monitor astronauts' bone status and prescribe preventive measures if bone loss is apparent.

To this end, Lang has been comparing ultrasound data from astronauts' heel bones (calcanei) with data from QCT examinations of their spines (vertebrae) and hips (upper femurs). "We wanted to see how ultrasound parameters reflect changes in bone mineral density at the heel and how heel measurements relate to measurements of the spine and hip," Lang says. The data so far have not been encouraging. They show that ultrasound measurements of the heel do not change significantly over the course of the mission, which is inconsistent with the QCT and DXA measurements at the hip and spine and even the results from DXA examinations of the heel.

While Lang delves deeper into bone's physical changes in microgravity, other researchers are examining biological changes in bone — specifically, how microgravity affects the absorption and metabolism of calcium. Still other researchers are focusing on bone preservation through resistance exercise and drugs for osteoporosis treatment. As they piece together the puzzle of bone loss in microgravity, the

continued on page 25

Wee Worms Yield Enduring Science

When Catharine Conley joined NASA in 1999, she fulfilled a long-held desire to work on the space program. Her research on tiny worms may one day show scientists how humans respond to gravity. The worms have already shown her that life can endure under the most remarkable circumstances.

Caenorhabditis elegans (*C. elegans*) may not seem like extraordinary animals to you and me. In the wild, they live freely in moist soil and rotting vegetation. They eat bacteria and fungi. They're not much to look at.

For scientists, though, these tiny roundworms (commonly called nematodes) yield a bounty of information in both fundamental and applied biology. Although *C. elegans* are not parasites, they are similar in biology to the parasitic roundworms that plague dogs and cats. While they are no bigger than a comma on the page you're reading, *C. elegans* have muscles, a digestive system, and a nervous system. One-third of their genes contain homologues — similar sequences — to human genes. Because of these similarities, some research done on worms can be applied to the study of human biology.

C. elegans may be a model organism for NASA as well. Biologist Catharine Conley uses the worms in her laboratory at NASA Ames Research Center in Moffett Field, California, to study tropomodulins, muscle proteins common to humans and animals. She also wants to identify any genes in *C. elegans* that respond to changes in gravity, which could help scientists understand how human biology changes while in microgravity (an important area of knowledge for the extended exploration of deep space).

Conley is principal investigator for several projects designed to support a space colony of *C. elegans*. She hopes that future scientists might use the worms to test potential drugs to counter some of the negative effects of spaceflight, such as motion sickness and muscle wasting — all of which can be translated directly into Earth benefits.

Worms are efficient subjects for studying these issues, but Conley first needs to understand their basic biology in microgravity and figure out how to grow them in this unusual environment. "You can't really plan the hypothesis for an experiment until you know the model system," she explains. "Any scientist has to calibrate equipment before an experiment. With worms, it's the same thing."

Recovery

Conley laid the groundwork for the first space shuttle experiment with a simple question: During spaceflight, could *C. elegans* survive on a formulated food instead of their usual diet of bacteria? Feeding bacteria to worms is labor intensive, and astronauts don't have time to spare during a mission. Conley wanted to replace the worms' food so the colony would not require tending. In her laboratory, the worms thrived on a chemical diet that she had read about in a scientific paper and modified, but she didn't know whether it would sustain them in microgravity.

In January 2003, after several years of ground-based experiments, Conley watched her worms lift off on Space Shuttle *Columbia* from Kennedy Space Center (KSC), Cape Canaveral, Florida. Unfortunately, that liftoff would be the shuttle

Investigator Catharine Conley and postdoctoral student Nate Szewczyk prepared an experiment to find the right food for growing a colony of *Caenorhabditis elegans* roundworms in microgravity. The researchers stand in front of a locker containing the canisters with the worms inside before the worms' flight on *Columbia's* last mission.

credit: Catherine Conley laboratory, NASA Ames Research Center

Caenorhabditis elegans roundworms squirm in a culture viewed under a microscope. These little worms may provide some genetic clues for the causes of astronaut health problems during spaceflight, such as muscle wasting.

credit: : NASA Ames Research Center

Columbia's last. Sixteen days later, as Conley listened from a hotel room near KSC for the sonic boom that heralds each space shuttle's return, a television report announced the unthinkable: There had been an accident; the space shuttle and crew had not survived reentry.

In the following weeks, five of her six experiment canisters were recovered from the *Columbia* debris field in Texas. For the spaceflight, Conley had packed culture dishes of *C. elegans* into six BRICs (Biological Research in Canisters). The BRICs, which are slightly smaller than coffee cans and made of sturdy material, were developed by KSC and had been placed in a locker on *Columbia* for the duration of the mission.

Because all hardware had been photographed before launch, the searchers identified the canisters as Conley's experiments. After weeks of inquiries, Conley learned that all but one of her canisters had indeed survived and had been transferred to KSC for storage. She was optimistic about the results. "Worms are small and dense, and their strong cuticle can withstand immense surface tension," she explains. "We were confident that the worms could survive as long as they didn't get overheated. Worms can't survive more than one half hour at 40 °C [104 °F]."

Conley intended to fly to Florida and open the canisters on Monday, April 29, 2003, but a tragic turn of events prevented her trip. On a California highway, traveling to the airport for her flight to KSC, Conley and two friends were involved in a car accident. One of Conley's friends was killed; the other and Conley were seriously injured. While Conley spent the next few weeks in intensive care, postdoctoral student Nate Szewczyk went to Florida, opened the canisters, and discovered that the worms had survived.

Near the end of May, Conley left the hospital. A few weeks later, pale and wearing a neck brace, Conley returned to work. She and her worms had made it. "It was touch and go for both of us," she says.

A dish to call home

On *Columbia*, the worms survived on the chemical diet that Conley had modified for the microgravity experiments. The diet had to sustain the worms throughout their life cycle. Under ideal conditions, *C. elegans* grow through four larval stages — from embryo to adult — in only 2 days. By day 5, they reproduce, then live for 2 to 3 weeks. They are able to progress through these stages only if a constant supply of food is available.

In laboratory cultures, *C. elegans* normally eat *Escherichia coli* (*E. coli*), a common bacterium. About every 4 days, the worms must be transferred to a fresh plate of bacteria, or else they enter a dormant phase until food again becomes available. Because transferring worms is a labor-intensive task, Conley had aimed to identify culture conditions that would extend the time that worms could remain in one culture dish so as to automate a future microgravity experiment.

The liquid diet that Conley modified is a combination of chemicals that contains all the nutrients the worms need but perhaps not what they like. When chomping on bacteria, *C. elegans* can get quite plump. In Conley's ground-based experiments, worms on the bacteria diet had fat globules in their digestive tracts, whereas worms on the chemical diet appeared slimmer, almost a little starved. Worms on the chemical diet lived longer, though — in fact, each stage from larva to adult was delayed, says Conley. Her lab has just completed a genetic analysis of worms that had been fed the chemical diet and is preparing the results for publication.

For the *Columbia* study, Conley set up and launched two similar groups of worms: one on culture dishes containing the chemical diet, and another on culture dishes containing *E. coli*. The worms that eventually were recovered from the space shuttle experiment appeared to have survived well on the chemical diet. Conley remarks, "The worms on the new media were actively reproducing, but the worms on the bacterial standard lab media were dauers [in a dormant phase]. We expected the bacterial plates to generate dauers in flight, since the bacterial food lasts less than a week."

Because the worm canisters were not recovered immediately, Conley was unable to obtain genetic data for any worms that flew on *Columbia* (that is, all of the worms that had been exposed to microgravity had reproduced and died by the time the canisters were recovered and subsequently examined). However, she hopes on future missions to examine whether worms fed the chemical diet undergo any genetic changes while in microgravity.

Caenorhabditis candid camera

Scientists already know a lot about the genetic makeup of *C. elegans*. All 19,000 genes have been sequenced, and all 939 cells have been studied extensively. So, Conley has a good starting point for studying how the chemical diet and changes in gravity will affect the worms.

Catharine Conley (Ames Research Center, Moffett Field, California) places a culture of *Caenorhabditis elegans* roundworms in a centrifuge for a hypergravity experiment. Conley hopes to observe changes in the worms' behavior under the altered gravity conditions.

credit: : NASA Ames Research Center

To study the genetic and behavioral effects of gravity, Conley is conducting a series of ground-based experiments using centrifuges, which produce increased levels of gravity (called hypergravity) by spinning. She places the worms in centrifuges and sets them to spin at different speeds and for different lengths of time. She also periodically turns the centrifuge off and studies how worms respond. "The change from high gravity to 1g [Earth's gravitational force]

continued on page 25

Liquid Crystal Bubbles: Platform for Molecular Research

Innovative research with bubbles of liquid crystals and "islands" on their surfaces allows scientists to probe fundamental questions about the physics of fluids and may lead to significant advances in display screen technology.

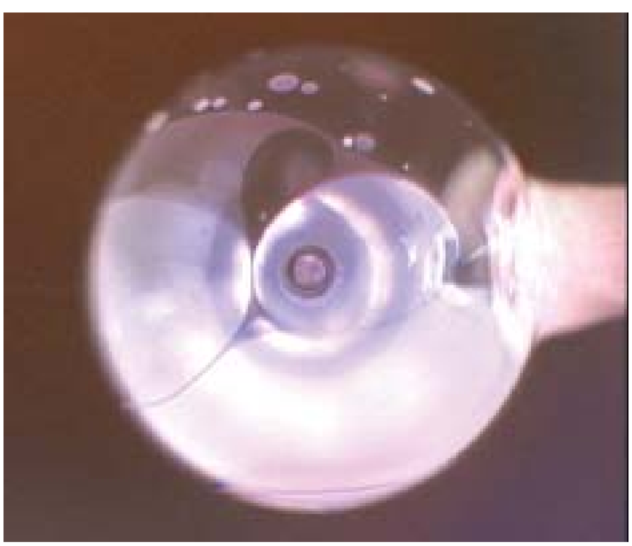
Remember blowing soap bubbles as a child? The fragile, short-lived spheres, showing off a rainbow of colors, inspired awe and wonder. Now a different and much more stable kind of bubble is helping researchers probe the physics of fluids and of liquid crystals. Noel Clark, a professor in the Physics Department and a member of the Liquid Crystal Physics Group in the Condensed Matter Laboratory at the University of Colorado at Boulder, is gaining insights into the behavior of molecular fluids from bubbles of freely suspended films of liquid crystals.

Liquid crystal displays (LCDs) are used in many common products — the screens in digital clocks, calculators, and laptop computers — because liquid crystals have special properties that make them useful in display technology. Certain configurations of liquid crystal molecules allow light to pass through while others block out light, and applying an electric field to the molecules changes their configuration and light-filtering and -blocking ability. Manipulating liquid crystals with electric circuits creates light and dark areas that can form numbers, letters, or pictures on a display.

To continue the current trend of producing LCD images that are smaller and sharper than ever before, additional basic understanding of liquid crystals is necessary. Clark describes his investigations as being at "the basic end of the scale" for research in the field, which runs the gamut from very fundamental scientific investigation of liquid crystals to major technical applications. Clark is trying to understand the physics of liquid crystal phases themselves.

To visualize the structure and behavior of liquid crystals, first imagine a large container half-full of Ping-Pong balls. Shake the container, and the balls tumble past each other, like the molecules in a liquid. Next, imagine those Ping-Pong balls spread out on a table in a single layer. The balls can still flow past each other, but they are constrained to horizontal movement along the tabletop. The balls behave like molecules of a liquid that can move in only two dimensions. Some liquid crystals exhibit this kind of order; they spontaneously organize themselves in two-dimensional sheets with liquidlike flow within each sheet. This arrangement is called smectic ordering. A liquid crystal may consist of many sheets stacked together, but its molecules do not readily move from sheet to sheet. Clark suggests that the "goo in the bottom of a soap dish" has this kind of structure.

One of the challenges of making LCDs is achieving a high degree of molecular alignment. A bulk sample of liquid crystal will typically contain places where the alignment is incomplete; these locations are called defects. A current difficulty in producing LCDs is that defects are created as the layers of liquid crystal form. The defects allow light to leak through, which reduces contrast on the display screen. If the defects could be eliminated, then the molecular alignment within the liquid crystal would be improved, resulting in a higher-quality display screen. At this point, exactly how to eliminate those defects is unclear. Clark and colleagues are probing the properties of defects in smectic liquid crystals. The insights they gain may assist researchers in devising ways to prevent defect formation.



A bubble of liquid crystal, about 1 centimeter (less than 0.5 inch) in diameter, is formed by pushing a small amount of liquid crystal through a syringe and then inflating it on the end of the needle. Such a bubble provides researchers with a unique platform for investigating fundamental questions about the physics of fluids.

credit: Liquid Crystal Physics Group, University of Colorado at Boulder

Blowing bubbles

The Liquid Crystal Physics Group at the University of Colorado at Boulder has been studying the physics of liquid crystal films for more than two decades, examining the details of their molecular structure and probing the structure and motion of defects. During the 1990s, the group performed pioneering work in producing bubbles of liquid crystal to be used as a platform for research.

This work stemmed from a unique approach to a known problem. Films of liquid crystal are ideal for basic investigation; they are so extremely thin that they can be treated as two dimensional, which gives researchers an object much simpler to work

No, this image is not of the innards of a lava lamp but the structure of a liquid crystal bubble. The interfaces of the circular "islands" (thicker regions) on the surface may provide Principal Investigator Noel Clark (University of Colorado at Boulder) with insights that could lead to eliminating defects in liquid crystal displays.

credit: Liquid Crystal Physics Group, University of Colorado at Boulder

with than a three-dimensional one. Working with films has one serious drawback, however: The frame that supports a liquid crystal film has an effect on the film's structure. To study molecules far enough away from the frame to eliminate this interaction, researchers would need a film with a fairly large area, but a film that is only a few molecules thick just couldn't hold together at the required area dimensions.

To get around this problem, Clark's group developed a way to create bubbles of liquid crystal. A small bubble, about 1 centimeter (less than 0.5 inch) in diameter, is suspended on the tip of a syringe, which means it only has one tiny point of contact with its support (rather than having a whole frame around it, as a flat film does). The bubble thus has much more area for studying the physics of the liquid crystal molecules without support structure interactions.

The Liquid Crystal Physics Group makes a bubble by pushing a small amount of liquid crystal through a syringe and then inflating the bubble on the end of the needle. This process is similar to blowing a soap bubble on the end of a straw. After the bubble is created, an air jet system puffs air onto the surface of the bubble to create "islands," circular regions that are thicker than the rest of the bubble. For example, a bubble that is predominately two molecules (or layers) thick may have an island that is three molecules thick. Because the bubbles are not susceptible to evaporation, Clark says that making films that are "perfectly happy for long periods of time" is a relatively straightforward process.

Clark studies the locations where the islands on a bubble contact each other. These interfaces are similar to defects, so understanding them will help researchers better understand defects in liquid crystals. Each island is effectively two dimensional, so the boundary between islands is only one dimensional. A one-dimensional system is the simplest possible case to study, test, and describe, thus facilitating the fundamental research that Clark's group is performing.

So far, Clark has been using these bubbles of liquid crystal to study general fluid physics — that is, examining the structure, hydrodynamics, and defect dynamics of the materials. To investigate defects, he must observe the very weak forces between islands. Ideally, he would study these forces without the competing effects of gravity. In the laboratory, gravity causes the islands to slide down to the bottom of the bubble. Studying bubbles in microgravity would provide researchers with a perfect situation: a two-dimensional system in which the islands remain distributed about the bubble, and a freely suspended bubble that lacks interaction with a support structure. Such ideal conditions have not previously been possible in physics experiments with thin-film fluids.

Advancing technology

Clark's work is supported by NASA's Office of Biological and Physical Research (OBPR), which has been sponsoring microgravity research on fluid physics for decades. Padetha Tin, project scientist with the National Center for Microgravity Research at NASA Glenn Research Center in Cleveland, Ohio, explains that Clark's current work and future microgravity investigations add to the fundamental understanding of the physics of liquid crystals, which will one day enable the development of advanced LCD devices that may be used on Earth and play a key role in the space program.

Francis Chiramonte, enterprise scientist for fluid physics with OBPR at NASA headquarters in Washington, D.C., explains that an important part of the display technology field right now is developing microdisplays that incorporate liquid crystals. Image quality is especially important in these applications because the screens are so small. Microdisplays are useful for near-eye screens, such as might be mounted inside an astronaut's helmet. Such a display could one day allow astronauts to do basic self-monitoring of their health without invasive techniques or doctor intervention. Perhaps a flip-down head-mounted display could "look" through an astronaut's eye and monitor blood sugar level, white blood cell count, protein levels, and other information that is typically part of a physical examination. Additional research with liquid crystals is needed to achieve this sort of application, but according to Chiramonte, researchers like Clark ultimately will determine how such an eyepiece might function.

Clark hopes to carry out his bubble experiments in microgravity later in this decade. He says he is "really appreciative of the NASA support. It has enabled us to do some of our best work."

Paige Varner

For more information about Noel Clark and the Liquid Crystal Physics Group at the University of Colorado at Boulder, visit *http://flcmrc.colorado.edu/*. Some of Clark's research is described in more technical detail in "Polarization-modulated smectic liquid crystal phases" (D. A. Coleman, J. Fernsler, N. Chattham, M. Nakata, Y. Takanishi, E. Körblova, D. R. Link, R.-F. Shao, W. G. Jang, J. E. Maclennan, O. Mondainn-Monval, C. Boyer, W. Weissflog, G. Pelzl, L.-C. Chien, J. Zasadzinski, J. Watanabe, D. M. Walba, H. Takezoe, and N. A. Clark, *Science*, *301*, 29 August 2003, pages 1204–1211). For more information about Clark's research as related to NASA's Fluid Physics Program, e-mail Mr. Padetha Tin at *padetha.tin@grc.nasa.gov*.

Television to the Max

Just as high-definition television is percolating onto commercial broadcast airwaves, an ultrahigh-definition camera named HD MAX is being developed for the International Space Station — and for more down-to-earth uses.

Imagine seeing the tiniest detail more clearly than ever on television — even several times better than possible with the hot new high-definition TVs (HDTVs). NASA research partnership centers in Florida and Texas are teamed with NASA and industry to develop just such technology: a lightweight, easy-to-use ultra-high-definition TV camera system called HD MAX that will fly aboard the International Space Station (ISS). HD MAX is expected to record scientific experiments on the ISS, but its main purpose is to chronicle the crew's activities in movies that will educate and inspire people on Earth.

"We are putting state-of-the-art imaging on the International Space Station for research, engineering, and public enjoyment," says Sherwood Anderson, special project manager in the Space Partnership Development Program Office at NASA Marshall Space Flight Center in Huntsville, Alabama. Anderson adds that in addition to recording crew activities on the ISS, HD MAX could improve the observation of flames and combustion, cell growth and division, propulsion system fluid flows, Earth (tracking the movements of phenomena such as dust storms), and processes by which molten metals and other materials solidify. He believes HD MAX ultimately might be used to monitor the robot arm during space shuttle flights, to observe activities on future robotic spacecraft missions to other planets, and to scan space shuttles for possible damage. The developers also expect that HD MAX will be used on Earth in Hollywood moviemaking, telemedicine, building security systems, and national security applications.

credit: Mardie Drolshagen Banks, Florida Atlantic University

Pioneering broadcast engineer William E. Glenn, director of the Imaging Technology Space Center at Florida Atlantic University, displays a prototype of HD MAX. He developed this ultrahigh-definition TV camera for use on the International Space Station, where it will record scientific experiments and crew activities.

HD MAX has 50 times better resolution (ability to detect detail) than a conventional color TV and several times better resolution than the newer home HDTVs. It is the highest-resolution TV camera available that can be adapted for use in microgravity, says its principal developer, William E. Glenn, a professor of electrical engineering and director of the Imaging Technology Space Center at Florida Atlantic University in Boca Raton.

Glenn worked from 1965 to 1975 for CBS Labs in Stamford, Connecticut, where he was director of research and vice president and helped design early TV cameras used for electronic newsgathering. Glenn is "arguably the nation's foremost broadcast television engineer," writes Joel Brinkley in his 1997 book about HDTV, *Defining Vision: The Battle for the Future of Television* (Harcourt Brace: New York).

Meanwhile, David R. Boyle, director of the Space Technology Center at Texas A&M University in College Station, is working to make sure that HD MAX is spaceworthy and that it has a power supply and a way to store the detailed images.

The centers directed by Glenn and Boyle are among the 15 research partnership centers supervised by NASA's Space Partnership Development Program Office. The centers — located at academic institutions and partially funded by NASA — work with private companies to develop new or improved products and services, often based on microgravity research. The corporate partners contribute to the cost.

"This project is an excellent example of the benefit to NASA of the … research partnership centers," says Boyle. "NASA is going to get this camera system for a lot less money than if they went out and asked a major aerospace company to build it."

A lot of pixels

HD MAX is the seventh in a line of prototypes, and "each one is significantly smaller and has better performance than before," Glenn says. The current model weighs 1.7 kilograms (3.75 pounds) and is the size of a camcorder: 7 centimeters wide, 11.4 centimeters tall, and 19 centimeters long (2.75 inches wide, 4.5 inches tall, and 7.5 inches long).

A typical home TV has a true resolution (the number of picture elements that effectively produce the picture, as opposed to the total number) of about 136,640 pixels, says Glenn. Home HDTVs have a true resolution of 924,000 pixels. HD MAX has 8,294,400 pixels in total — almost 8.3 megapixels — with a true resolution of about 7 megapixels. "It's as if you took 50 standard television sets and nested them in a big wall," Glenn explains. "Lots of cameras that take still pictures have higher resolution. The highest is about 16 million pixels, but they are not video cameras and cannot run moving images."

HD MAX uses complementary metal oxide semiconductor (CMOS) image sensors, which are less expensive, easier to make, more sensitive, generate less "white noise," and use less power than conventional charge-coupled device (CCD) sensors. CMOS sensors should be able to survive levels of radiation inside the ISS for up to 10 years, whereas typical CCDs begin to deteriorate after only a few weeks, Boyle says.

Boyle's center will test HD MAX to learn whether any parts must be modified to withstand cosmic rays and other radiation while in orbit. "But the main challenges are in cooling the camera," Boyle says. "On Earth, we have gravity, so if something gets warm, the air next to it absorbs some of the heat and rises, and fresh air takes its place. In the space station, there is no gravity, so the air near a hot surface stays put and just gets hotter and hotter. That makes the camera get warmer than it does on Earth." Boyle's team performed a computer simulation of HD MAX heating that helped them decide how to reposition internal fans and components to improve cooling.

David Boyle directs the Space Technology Center at Texas A&M University. The center is building the locker that will provide power to HD MAX (an ultrahigh-definition TV camera developed for use on the International Space Station) and hold hard drives to record images. Boyle is shown with a prototype star tracker that includes optics and electronics he says are closely related to HD MAX.

credit: Kim Miller, Texas A&M University

The box behind HD MAX

Boyle's center is also building a locker or "base station" for HD MAX that will nestle among the eight lockers that fit inside one EXPRESS (EXpedite the PRocessing of Experiments to the Space Station) rack in the U.S. Laboratory module of the ISS. EXPRESS is a standardized payload rack system that transports, stores, and supports ISS experiments. The HD MAX locker is about 43 centimeters wide, 51 centimeters deep, and 25 centimeters tall (17 inches wide, 20 inches deep, and 10 inches tall). It will contain connections to electric power, a computer processor, fans to cool the computer, hard drives to store images from HD MAX, and pipes and radiators to circulate water to cool the hard drives. HD MAX will be tethered to its locker by cables to carry power and data.

Multiple hard drives are necessary because HD MAX collects a huge amount of data — 3 gigabits (3 billion bits) of image data per second. "It's a fire hose of data," says Glenn. The highest-resolution TV pictures cannot be transmitted from the ISS to Earth, because the volume of data is far greater than the radio downlink can handle, but he adds, "you can grab a frame of the moving image and send that down at full resolution."

Each package of eight hard drives is known as a RAID (for "redundant array of independent drives"). "It's basically a stack of hard drives," Glenn explains, each of which stores up to about 30 minutes of the camera's recording time in a fairly small device. Each ISS crew would bring three such packages, allowing for up to 90 minutes worth of TV pictures of crew activities. Anderson says scientists who use HD MAX to record science experiments will have to send additional hard drives with their own equipment.

Low-resolution images from HD MAX can be transmitted to Earth, allowing scientists or others on the ground to edit the content so only desired images are stored on the hard drives. Glenn estimates the camera therefore could shoot 10 times more images than are ultimately recorded on the hard drives and taken back to Earth. Scientists simply would pick the one-tenth of the images worth saving.

From Hollywood to NASA

Glenn hopes that HD MAX ultimately will be used for "making movies on the ground. The entire motion picture industry is going to go digital in the not-too-distant future." He says that his lab has been in "serious discussions" with companies that lease moviemaking equipment to film studios. Movies made with HDTV cameras "would be sharper, with less film grain," he says. Initially, the TV pictures likely will be transferred to 35-millimeter film and perhaps even 70-millimeter film. "Eventually, when you get electronic projectors everywhere, there will be a tremendous improvement in image quality," he adds.

The camera also might be used for telemedicine, in remote regions on Earth or during spaceflight, says Anderson. "You can produce outstanding images of any sort of injury so a physician on the ground might tell someone what to do about it," Glenn says.

In addition, Glenn expects that HDTV will be used in manufacturing. "More and more things are manufactured by machine, and you have to be able to locate parts and position them very accurately on another part," he says. "This is often done with a camera automatically; the higher the resolution a camera is and the higher [its] frame rate, the more accurately and faster you can do it."

Glenn foresees wide-ranging use for HD MAX in improving video surveillance for use in casinos (to identify cheaters), stores (to record robberies), and military facilities (to monitor against attacks). He says the U.S. Department of Defense funded development of earlier versions of HD MAX because the military wants to be able to detect potential threats like the October 2000 attack in which terrorists drove a motorboat full of explosives into the USS *Cole* while it was mooring in a Yemen port. With HD MAX, military personnel should "be able to recognize that [threat] at a lot longer distance than they have in the past," Glenn says.

NASA may have another important use for the camera. HD MAX "is being proposed as a candidate to help inspect space shuttles" to look for the kind of external damage that led to the *Columbia* tragedy, Anderson says. Glenn adds that the camera could be used to observe space shuttles during launch or during docking with the ISS.

Lee J. Siegel

For more information about William Glenn's early work on high-definition television cameras, visit *http://www.fau.edu/divdept/comtech/ctchome.html*. For information about the Spacecraft Technology Center at Texas A&M University, see *http://stc.tamu.edu*. For information about activities at NASA research partnership centers, see *http://spd.nasa.gov.*

Three Touched by Space Touch the Future through Teaching

Fortuitous brushes with space-related events and activities led three teachers to discover how drama in orbit can inspire students in elementary school, high school, and college.

The *Challenger* disaster … the Apollo 11 crew landing on the Moon … a two-year sabbatical spent doing NASA space research. These three widely different experiences inspired three teachers to become involved with the space program — and take their knowledge back to the classroom.

Destinies crossed

On January 28, 1986, 11-year-old Shelly Clark watched on television as Christa McAuliffe — her new-found heroine and the first teacher to launch into space — lifted off aboard the Space Shuttle *Challenger*. Ever since seeing the first space shuttle launch when she was 6, Clark had yearned to be an astronaut.

As *Challenger* climbed higher, muffled explosions sent white smoke into an unexpected arc through the sky. Then NASA's Mission Control announced, "We have a major malfunction." Watching pieces of the space shuttle raining down from the sky, Clark realized she had just witnessed the death of her heroine. Still grieving over the tragedy, Clark wrote all of her research papers in junior high and high school about Christa McAuliffe and *Challenger*. Then she went to McNeese State University and majored in early childhood education, seeking to follow in McAuliffe's footsteps.

Fifth-grader Michael Edwards works on designing a space vehicle capable of safely landing an "eggnaut" — a raw egg "astronaut" — dropped from above his head. Because the theme of Langston Magnet School is environmental studies and aerospace, teacher Shelly Clark's classroom abounds with space-related objects, including a glovebox built by the students (far right) and a "space shuttle" built from a refrigerator box (rear center).

credit: Shelly Clark, Langston Magnet School

In 1997, Clark began teaching elementary grades at her childhood alma mater, Singer High School (which, despite its name, includes kindergarten through grade 12), in the small town of Singer, Louisiana. Like McAuliffe, she yearned to be involved with space. So, she attended educational conferences at Johnson Space Center in Houston, Texas. Back in Singer, she incorporated as much information about space as she could into her classes. Then, in 2001, she learned about a position in Hot Springs, Arkansas, at the Langston Magnet School — an elementary school whose curriculum revolves around aerospace and environmental studies. "That just rang my bell," Clark says. She sent off her résumé and was selected for the job.

Clark has found her dream job. Science lessons at Langston revolve around physics and biology in microgravity. Reading lessons feature biographies of astronauts and other space pioneers. The fifth grade's major annual field trip is a week of Space Camp at the U.S. Space and Rocket Center in Huntsville, Alabama. Normal classroom activities include teleconferencing with NASA's Mission Control for International Space Station (ISS) missions and watching live space shuttle launches and returns.

Thus it happened that on January 16, 2003, Clark's fourth-grade class viewed the launch of the Space Shuttle *Columbia* for STS-107. They even spoke with Mission Control the day before the *Columbia's* anticipated landing on Saturday, February 1, and looked forward to discussing the mission the following Monday.

When the *Columbia* did not reemerge from radio silence and, once again, the TV showed debris raining from a blue sky, Clark wondered how she was going to face her students.

Monday morning, Clark arrived early. She realized that she had been scarcely older than her students when she had witnessed the *Challenger* disaster. Suddenly, recalls Clark, "there was no doubt in my mind that here is where I was supposed to be." She knew that she could help her students deal with their grief.

The children wrote letters to the astronauts' families, created a banner for the Houston Manned Space Flight Center, and wrote essays. Struck by Clark's story of how her own grief over *Challenger* enabled her to help her own students deal with the loss of *Columbia*, independent filmmaker Josh Baxter produced a documentary film, *Destinies Crossed*. It has been shown in classrooms and was submitted to the Columbia Accident Investigation Board. (The documentary also helped Clark win the World Space Week 2003 Teacher Award, to be presented in April 2004.)

Most significantly, although saddened by the *Columbia* tragedy, the students were inspired by the astronauts, just as Clark had been inspired by Christa McAuliffe years earlier. Several weeks after *Columbia's* disintegration, then fourth-grader Mike Edwards approached Clark and said quietly, "I've been thinking. I want to carry on Rick Husband's legacy. Can you help me write a letter to the governor to ask what I have to do to become an astronaut?"

Making learning "real"

Ever since witnessing the crew of Apollo 11 walking on the Moon in July

1969, Patrick Daugherty has been, in his words, a "NASA addict." After earning a master of education degree in technology in 1973, he began teaching technology at Rock Bridge High School in Columbia, Missouri. In the evenings, he followed the progress of NASA's manned and unmanned space missions. Seeking ways to excite students about technology and to include science in his course content, Daugherty attended a 2-week workshop for teachers at NASA Marshall Space Flight Center in Huntsville, Alabama, in the summer of 1990. There it struck him: Why not include aerospace concepts and activities in his classes?

Several student "astronauts" are shown inside a half-scale model of the International Space Station built by the Columbia Aeronautics and Space Administration in Columbia, Missouri. They work at computers that store the schedule for the "mission" as well as directions for conducting experiments and schedules for live TV broadcasts. Their blue jumpsuits sport the Canadian flag as well as NASA patches because this crew includes six students from Quebec, Canada.

credit: Patrick Daugherty, Rock Bridge High School

Because Daugherty wanted to give his students (grades 10–12) hands-on motivation to learn science and technology, he founded the Columbia Aeronautics and Space Association (CASA). Students in the program built a half-scale, three-module lunar habitat — a command module, a science module, and living quarters — and a "mission control" center. During spring break 1991, 20 student "astronauts" took turns simulating activities in the habitat for 3 days, 24 hours a day. Televised live over public-access TV, the students' activities included conducting science experiments, preparing meals, recycling water for bathing, and presenting lesson plans to two elementary schools. The climax was a live teleconference with former Apollo astronaut James Lovell.

At the end of the year, Daugherty was exhausted but ecstatic at how the project "motivated students who might otherwise skip the course in science and technology or not get much out of it." In fact, over the next decade, CASA became increasingly ambitious. The habitat's 3-day mission over spring break was extended to 1 week to allow more students time to participate. Student "astronauts" experienced neutral buoyancy training in the school swimming pool, and local private pilots took them up in small airplanes to experience moments of freefall during parabolic flight.

Meanwhile, the habitat itself was transformed into a scale model of the ISS; a space shuttle orbiter on a motorized cable ferried changes in crew, supplies, and experiments. Outside the habitat, students replicated Mission Control at the Johnson Manned Space Flight Center, Houston, Texas, using NASA jargon to communicate with the "astronauts." Other students designed unscheduled simulated on-board emergencies. Student "astronauts" and "ground crews" learned how to diagnose and resolve emergencies such as a stopped ventilator fan or a drop in internal temperature. Still other students role-played NASA's public affairs offices: They wrote press releases and sent them to other schools and to newspapers and TV stations, which subsequently interviewed CASA participants; TV cameras broadcasted the "mission" live to local elementary schools.

As the project grew, Columbia's Hickman High School became the permanent home to the scale-model ISS and orbiter, and two other teachers — James Kyd and now Fred Thompson — have succeeded Daugherty as director of CASA. Local businesses donated goods, including sheet metal for "space vehicles," as well as funds for astronaut jumpsuits, food, and NASA software. Today, the student "astronauts" even run simple on-board biology experiments. Fulfilling a vision that began with the first "mission," students from other states and even Canada now are guest "astronauts" with CASA.

Although Daugherty, Kyd, and Thompson have ensured that CASA reflects the objectives of state and national educational standards, Daugherty feels its greatest value is in offering "authentic, problem-solving, student-directed research as real as you can get in high school." Most gratifying of all, he adds, the program has "made a difference in the lives of my students. You can see it in their eyes. Learning becomes real; they can see why science and technology are important beyond the classroom."

Creating a bridge

It's never too late in life to be inspired by the space program. That's the message from Benita Bell, associate professor of chemistry at Bennett College for Women in Greensboro, North Carolina. Bell became involved with NASA for the

continued on page 26

Space Radiation Research Takes a Giant Step Forward

With the official opening of the NASA Space Radiation Laboratory at Brookhaven National Laboratory in New York, NASA researchers have gained access to a dedicated facility for radiation research — research that is essential for ensuring human safety in space.

The major limiting factor for humans safely living and working in space is the risk of radiation exposure. The Earth's magnetic field shields crewmembers on the International Space Station (ISS) from the worst effects of space radiation. However, beyond low Earth orbit, humans are at an increased risk of developing cancer from radiation exposure. By learning more about how radiation-induced cancer develops, NASA researchers hope to minimize this risk to space travelers while helping people who have cancer on Earth.

Space radiation consists mainly of ionizing radiation in the form of charged atomic nuclei that travel at close to the speed of light. Although the heaviest of these, called HZE particles, account for only 1 percent of galactic cosmic rays (GCRs; the primary radiation source in space), they have the greatest potential to cause damage to humans because of their high energy and charge.

The atoms in shielding materials slow down and undergo nuclear reactions with charged particles. The amount of material required to stop most HZE particles far exceeds the mass that can be carried by practical spacecraft, and the likelihood of creating undesirable reaction products from the material increases with thickness. Currently, the only way to protect humans against GCR radiation is to limit radiation exposure — for example, by using shielding materials and by scheduling spacewalks only when the spacecraft is in a region of low radiation. Because the biological effects of HZE exposure are poorly understood, shielding and other protective measures must be substantial enough to allow an adequate safety margin until practical medical strategies are devised for reducing the effects of radiation on health. Meanwhile, researchers seeking to protect organisms against exposure to space radiation also are trying to understand the most basic effects of radiation.

credit: Courtesy of Brookhaven National Laboratory

NASA Space Radiation Laboratory (NSRL) researcher Debasish Roy places a sample into the NSRL beam line.

NASA researchers have conducted radiation research on Earth since the 1970s (see "Fire and radiation safety get new emphasis from space research" in *Space Research*, *1*(1), 2001, page 6). According to Walter Schimmerling, program scientist for NASA's radiation programs at NASA Headquarters in Washington, D.C., "We've known for a long time that you can simulate most of the components of space radiation on the ground, and therefore you can do all your basic radiation science on the ground without putting humans at risk."

However, by 1998, the only facilities available for GCR radiation research were two accelerators at Brookhaven National Laboratory in Upton, New York. The Alternating Gradient Synchrotron provided only the high-energy part of the spectrum; the Booster Synchrotron provided most of the particle energies and ranges that NASA researchers required, but its design did not allow researchers access to the radiation beams.

Schimmerling and NASA colleagues began negotiations with the U.S. Department of Energy (DOE), which manages Brookhaven, to modify the Booster Synchrotron to provide the entire spectrum of space radiation to researchers. In 1998, NASA and DOE signed a memorandum of understanding for the needed modifications and construction at Brookhaven, and the project was put in motion. The NASA Space Radiation Laboratory (NSRL) was completed on time and within budget in June 2003, and the laboratory opened for business in October 2003.

In 2002, the U.S. Congress signed the Space Radiation Initiative (SRI), primarily to fund ongoing ground-based research at NSRL. Augmenting the radiation research program within NASA's Office of Biological and Physical Research (OBPR), SRI is intended to enable investigators to accomplish the first goal of the program: to reduce uncertainties in risk prediction and to expand radiation protection strategies so astronauts can safely accomplish up to three 180-day ISS missions without exceeding their career radiation limits.

The radiation research program is managed by a space radiation research board that includes representatives from each of the OBPR research divisions and from the lead NASA centers responsible for implementing the components of the program. The board develops strategies and budgets and oversees research, placing individual OBPR division responsibilities under a joint strategy umbrella.

Space radiation research crosses all divisions within OBPR, and NSRL truly is an interdisciplinary facility. "People are doing experiments with materials or with animal (including human) cells or tissues," says Schimmerling. "[They are] trying to look at different parts of a common puzzle." For example, researchers in materials science are investigating how incident radiation (which hits an object directly) interacts with various materials; they are especially interested in determining which types of materials normally used in spacecraft construction also shield against space radiation. Biology researchers are looking at the basic mechanisms of deoxyribonucleic acid (DNA) damage by radiation and how DNA can repair itself. Biomedical researchers are trying to determine how space radiation causes cancer in humans to reduce the risk to deep space explorers; their findings may be transferable to different kinds of cancer on Earth.

Schimmerling hopes that the successes of NASA researchers using the NSRL facilities will stimulate other researchers to become interested in radiation research, which would benefit not only the facility and the field but also the people who explore the universe.

Julie K. Poudrier

For more information about the NASA Space Radiation Laboratory, visit http://server.cad.bnl.gov/esfd/nsrl/operations/index.html. For additional information about the Office of Biological and Physical Research's radiation research program, visit http://spaceresearch.nasa.gov/research_projects/radiation.html.

***Bone Loss* continued from page 15**

researchers have little doubt that they'll be able to minimize if not eliminate it for future spaceflight crews. "Mars is the next frontier," LeBlanc says. "Eventually, we will go. By then, I'm sure the bone problem will be a nonissue."

When astronauts return from their first trip to the Red Planet, LeBlanc and Lang expect to see them coming back as fit as the day they left — inside and out.

Cynthia Washam

To learn more about the effects of microgravity on bone density, visit http://science.nasa.gov/headlines/y2001/ast01oct_1.htm. For more information about Lang's research, visit http://hrf.jsc.nasa.gov/science/e343.htm.

***Wee worms* continued from page 17**

would be similar to what astronauts experience as they go from 1*g* to the low gravity of orbit," she explains.

Conley has begun studying the genetic profile of worms subjected to hypergravity experiments, but the experiments and analyses are not complete. Until then, she is observing and characterizing behavioral changes in worms while they are in the centrifuge. "We wouldn't predict that the behavioral alterations would be directly caused by differences in expression of one gene, but we do anticipate that they might indicate specific changes in how the neuronal circuitry is controlling movement," she says.

Conley has just begun experiments in which she observes the worms during hypergravity experiments with the use of a custom-designed still camera about the size of an ice cube. Students at Harvey Mudd College in Claremont, California, built the camera as a senior project. Conley also uses a video system that tracks the worms during centrifugation and transmits real-time images.

A trip back to space

Conley doesn't know when more worms might take a trip to space, but that doesn't mean that her experiments are stalled. She is developing automated culture hardware in collaboration with Gregory Kovac's lab at Stanford University, Stanford, California, that could be used to support a space colony of worms. She also plans to conduct freefall balloon and satellite experiments to test the technical aspects of her hardware in 2004. The balloon will provide low-gravity conditions during 30 seconds of freefall, and the satellite will provide weeks to months of low gravity.

Eventually, Conley would like to see a colony of *C. elegans* sent to the International Space Station for a stay of months or even years. Were that to happen, she could investigate how tropomodulins function in microgravity. Sustaining the worms on such a long stay in orbit shouldn't be difficult. Conley has enough data from the *Columbia* experiment to convince her that the chemical diet will sustain worms during future missions, even indefinite stays in orbit.

On the personal side, Conley faces additional surgery to repair lingering injuries from her own accident. And neither *Columbia* nor the car accident is a closed issue for her. "Even now," she comments, "I have the loss of my friend and the loss of *Columbia* all confounded in my emotions with the survival of the worms."

Jeanne Erdmann

To learn more about Catharine Conley's research, go to http://lifesci.arc.nasa.gov/conley/home. To learn more about *Caenorhabditis elegans*, visit http://www.biotech.missouri.edu/Dauer-World.

Touched by Space continued from page 23

credit: Benita Bell, Bennett College for Women

Professor Benita Bell (center, in blue) from Bennett College for Women in Greensboro, North Carolina, and students from Bennett and various other colleges listen to a guide explain the structure of the Stanford Linear Accelerator in an exhibit at Stanford University, Stanford, California. The Bennett students were in California as part of a research academy at NASA Ames Research Center, Moffet Field, California, in the summer of 2003.

first time in her thirties, and the students she introduces to aerospace research are college undergraduates.

The child of two Bennett College professors, Bell grew up playing with chemistry sets and telescopes but had many wide-ranging interests. She earned a bachelor's degree with a double major in French and chemistry, then a master's degree in chemistry before going into pharmaceutical sales. Subsequently, she earned her doctorate in chemistry. In 1990, she joined Bennett's science division, the largest division in the 600-student liberal arts college.

After several years of teaching, Bell began seeking ways that she and her students could become more involved with cutting-edge scientific research. In 1999, she learned about a program (sponsored by what is now the Office of Biological and Physical Research [OBPR]) that offered faculty from historically Black colleges the opportunity to spend 2 years working alongside NASA scientists. Bell soon was splitting her time between NASA Headquarters in Washington, D.C. (learning about NASA space science policy and administration, especially at OBPR), and several NASA field centers and universities (doing NASA-sponsored research).

On her return to Bennett College in September 2002, Bell instituted an annual series of four NASA Distinguished Lectures, during which NASA scientists spend a few days at the college speaking about their research and meeting students. That same year, Bell began an annual NASA Space Science Week designed to educate students in kindergarten through grade 12 as well as the public at large. NASA Space Science Week in March 2003 focused on astrobiology, molecular biology, engineering, and forensic science and attracted more than 1,000 attendees.

Now, Bell seeks ways for her students to do research at NASA field centers during summers. She also is working with NASA to create 15-hour minicourses at Bennett on NASA's cutting-edge space research in astrophysics, genetic engineering, and geoscience. For each 2-week minicourse, NASA scientists and two professors from Tennessee State University will teach or conduct labs, and students will be able to earn 1 hour of credit.

When NASA representatives visit Bennett, Bell likes to stand in the back of the room and observe her students react and interact with them. "I especially notice how their interest piques when they see someone who looks like them — young, female, or Black. It helps them say, 'I can do that!' which may lead them to say 'I want to do that, too!'" She smiles. "It's more than just teaching; it's connecting with the students. It's a human being creating a bridge."

Trudy E. Bell

To obtain a copy of the 1-hour video *Destinies Crossed*, contact Josh Baxter, Arion Pictures, Hot Springs, Arkansas, at (501) 282-0143, arion674@aol.com, or arion 674@hotmail.com. For more information about the Columbia Aeronautics and Space Association, including images of the International Space Station model, visit http://teachers.columbia.k12.mo.us/hhs/fthompso/casa.

Donald Pettit

Donald Pettit, who was science officer for Expedition 6 on the International Space Station, can't wait to return to orbit. While in microgravity, he conducted a series of "Saturday Morning Science" experiments with "jaw-dropping" results.

credit: NASA

Astronaut Donald Pettit hardly had regained his Earth legs when he was ready to return to orbit. "We'd make some amazing discoveries," he enthuses about conducting experiments aboard the International Space Station (ISS). "Space is just such an exciting place that there's no way I would ever get tired of the environment. If we had the technology, I'd load up my family and move into space and never come back to planet Earth."

That's heady commentary from a chemical engineer who initially was part of the backup crew for Expedition 6. Pettit subsequently became the ISS science officer and spent almost 6 months on the mission, during which he took two spacewalks, performed maintenance on the ISS, and conducted prescheduled as well as informal science experiments. Pettit was excited to put to work his chemical engineering education and his experience at Los Alamos National Laboratory (New Mexico) and at NASA Johnson Space Center (Houston, Texas). The Expedition 6 crew was launched on November 23, 2002, on the Space Shuttle *Endeavour* and returned to Earth on a Russian Soyuz spacecraft.

For Pettit, the mission was a fascinating experience filled with opportunities — many with unexpected results. He ran his own experiments, such as examining crystal growth, as well as ones that were carefully crafted in advance at NASA centers. Some of the experiments are ongoing among various ISS crews, such as research on muscle weakening and kidney stone formation in microgravity. Discovering how to combat these problems could not only enable deep space exploration, but also serve to improve human health on Earth. Experiments done in microgravity, he says, provide useful information to scientists on Earth, because it is possible to see the nature of forces normally masked by Earth's gravity.

Pettit lights up when he talks about a special group of discretionary experiments that he conducted for a university-level audience on Earth. They became known as Saturday Morning Science and included experiments on surface tension, bubbles, smell, and auroras. Astronauts usually have little free time on missions, but because earlier crews already had built most of the ISS, Pettit says that he had time for on-the-fly experimentation. Knowing Pettit's curiosity and passion for exploring, the other crew members also helped make time for him to run his own experiments — 20 in all — on top of his normal workload.

"In a space environment, you don't have good intuition for what goes on because it's so radically different from what we are used to on the ground," Pettit says. "It's an environment ripe for discovery." The Saturday Morning Science experiments, which were videotaped and downloaded to Earth, were based on unexpected observations that surprised Pettit — things that happen in microgravity in a way he simply didn't expect.

He calls one such experiment "The Invisible Spoon of Marangoni." Marangoni convection is an obscure phenomenon whereby a change in temperature alters the surface tension of a liquid, thereby causing convection. This circular movement, in which the liquid appears to be stirred by an invisible spoon, is difficult to observe on Earth because gravity and surface tension typically maintain a subtle balance — so, for example, the surface of water in a glass looks flat. But in a weightless environment, Marangoni convection is easier to see.

While conducting an experiment on the diffusion of a stagnant film of water created on a small wire loop, Pettit shined a tiny flashlight on the film to see what was happening. To his surprise, within a few seconds, the water film began to move in a Marangoni convection. On Earth, higher temperatures are needed to change the surface tension to cause this movement, but in this case, the heat of the tiny flashlight caused the phenomenon. "The heat was being magnified because the forces that normally mask it had been removed," says Pettit. "This heat was enough to drive a Marangoni convection, and that really was a jaw-dropping moment. So, what started as a diffusion experiment changed into a convection experiment."

This is what Pettit calls science of opportunity; it's exciting because it's unexpected. Had he proposed such an experiment before his trip to the ISS, it likely would have been nixed, because scientists on Earth simply couldn't conceive that such a phenomenon would occur. "Mother Nature has a vivid imagination, more so than we human beings," says Pettit. "The only way we'll know what she has in store for us is to seek it ourselves."

Lori Valigra

For more information about Pettit's experiments, *visit http://spaceflight.nasa.gov/station/crew/exp6/spacechronicles.html* and *http://search.nasa.gov/nasasearch/search/search.jsp?nasaInclude=Saturday+Morning+Science.*

National Aeronautics and
Space Administration

Marshall Space Flight Center
Building 4201, SD13
Marshall Space Flight Center, AL 35812

PRSRT STD
U. S. POSTAGE
PAID
NASA
Permit No.G-27

Space Research

Office of Biological and Physical Research

http://spaceresearch.nasa.gov